ESD-TDR-64-134 SR-110

A PRELIMINARY GEOLOGIC ASSESSMENT OF SELECTED SITES IN THE UNITED STATES THAT MAY BE SUITABLE FOR DEEP UNDERGROUND COMMAND AND CONTROL CENTERS

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-64-134

JUNE 1964

G. A. Kiersch, Consulting Geologist
W. D. Gunther

Prepared for

DEPUTY FOR ADVANCED PLANNING
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 612.1

Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-2390

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FOREWORD

One of the concerns of the Mechanical Systems Sub-Department at MITRE has been the assessment of physical survivability of command and control systems in a nuclear environment.

The four approaches to survivability, namely, hardening, dispersion, redundance, and mobility, have been investigated to varying degrees.

During the period from 1960 through early 1963, considerable interest was shown by the various system groups in hardening by going deep underground. Hence, this approach received special emphasis in the Mechanical Systems Sub-Department. At one time, one of the important questions was the following: "What are promising sites in the U.S. where a DUSC (Deep Underground Support Center) could be located with approximately 5000 feet of cover?" Since there are literally hundreds of "possible" sites (at least on the basis of a cursory look), a rational approach seemed to be one based on a process of elimination.

There are many factors which would make such sites impractical. From a <u>cost</u> and <u>feasibility</u> point of view, however, geological and construction aspects in combination may represent the most important if not overriding consideration. It is not inferred that if a site is desirable from a geological/construction point of view, it is in effect an ideal location for a command and control center. Other considerations; e.g., functional, may render the site useless. It <u>is</u> inferred, however, that if a site with about 5000 feet of cover is impractical on the bases of geological construction feasibility and cost considerations, it must be eliminated. Hence, it was felt that a survey of promising sites on such bases was called for, since it could narrow the otherwise unmanageable number of possibilities.

Such a survey was undertaken, and the results are summarized in this report.

At present, no DUSC is being funded, yet discussions of their advisability continue. In some measure, this report should help to put these discussions on a more meaningful basis.

Gabor Strasser

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ABSTRACT

A PRELIMINARY GEOLOGIC ASSESSMENT OF SELECTED SITES IN THE UNITED STATES THAT MAY BE SUITABLE FOR DEEP UNDERGROUND COMMAND AND CONTROL CENTERS

In the past few years, considerable emphasis has been placed on the hardening of military command and control centers by constructing large cavities deep underground. To a large degree, the feasibility of such construction depends on the existing geology at the required depth. This document suggests a general procedure for the preliminary geological assessment of any deep underground site, and the method is applied to sites within the United States that could provide an arbitrary depth of 5000 feet of suitable cover. Thirteen of the sites selected are further evaluated in the light of geology, logistics, and other military considerations, and rated accordingly.

REVIEW AND APPROVAL

Publication of this technical documentary report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

F J Dillon Col,

FRANCIS J. DILLON, JR.
Colonel, USAF
Director of Analysis
Deputy for Advanced Planning

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SECTION I

INTRODUCTION

Post-nuclear attack system operational capability has become a matter of importance to military system planners. Command control system designers have often turned to protective construction, or hardening, as a means of assuring such system survivability under nuclear attack. Hardening methods have varied from cut-and-cover* to excavation of a cavity in solid rock. Examples of the former are the Titan missile facilities; an example of the cavity excavation technique is the NORAD installation being constructed in Cheyenne Mountain, Colorado.

In the last several years the nuclear threat to command control systems has significantly increased with the advent of high yield, accurate weapons. This threat escalation has forced the system planner to consider placing underground installations at depths of several thousand feet to insure their survival.

In general there are two major methods by which several thousand feet of cover may be obtained. In essentially level terrain it is necessary to sink a vertical entrance shaft to the desired depth before excavating the cavity to house the installation. This method has several disadvantages, such as high cost of excavation and construction. A more practical method for obtaining large depths of cover is to locate the installation under a mountain where horizontal access to the cavity can be provided.

An inventory of areas with high topographic relief was prepared for The MITRE Corporation in 1962.[1] These sites, however, are characterized by a minimum cover of 2000 feet; this may not be sufficient protection against a high-yield attack. Also, most of the available

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*A structure is built just under the ground surface and the excavation is backfilled to completely cover the building with earth.

information on selection of underground sites is limited to geological conditions within 1000 feet of the surface. Such studies are important to the design and location of access portals to a cavity located at depths greater than 1000 to 2000 feet, but they are not adequate for site selection for such cavities per se. Hence, the purpose of this report is to develop a general procedure for the preliminary geological assessment of any deep underground site, and subsequently to apply this procedure to sites available in the continental United States that would provide at least 5000 feet of suitable geologic cover using a horizontal tunnel access. The 5000 foot criterion is arbitrary; it should, however, be representative of the depth of cover required to withstand the threats postulated. Application of the preliminary site assessment criterion (in conjunction with other criteria listed below) to these possible sites resulted in the selection of thirteen sites that appear adequate for location of a deep underground installation. These thirteen sites are then further evaluated in the light of geology, logistics, and other military considerations and rated accordingly.

The remaining parts of Section I of this report present the conclusions of the study (i.e., the ranking of the thirteen potential sites), the method of preliminary site assessment, some considerations on geology for deep underground cavities, and comments on site exploration. Section II contains the detailed evaluation of the thirteen sites.

CONCLUSIONS

From the standpoint of geology alone there are many places within the United States where a deep underground cavity could be located. However, military siting depends on a number of equally important factors that narrow the choice of sites to relatively few. Some of these factors are:

1. access to major transportation arteries,

2. re-supply and other logistical problems,

3. length of horizontal tunnel to obtain adequate cover, and

4. proximity to a suitable communications net.

A prior study of areas with high topography in the United States[2] was reviewed using the principles established in this report for making a preliminary geologic assessment of potential sites for underground military support centers. Further, an additional set of criteria was assumed as follows:

1. The excavated main cavity must be entered by a horizontal access tunnel.

2. The horizontal access tunnel must not exceed a length of two nautical miles.

3. The access tunnel must not exceed a gradient of -10% from the entrance portal.

4. Depth of cover for the installation must be at least 5000 feet from any point on the surface.

5. The potential location must satisfy the majority of military siting objectives.

6. The proposed cavity excavation must have at least 1000 feet of structurally sound rock cover.

7. An attempt should be made to locate at least one site in the five geographical regions of the United States, viz., Northeast, Southeast, Southwest, Northwest, and Alaska.

The thirteen sites thus determined (Fig. 1) are discussed in detail in Section II of this report and are considered the best potential locations for a deep underground support center (DUSC) based on the

Fig. 1 **GENERAL LOCATION MAP**

stated criteria. A relative rating of the sites as to geology, logistics, and other military considerations is tabulated below:

Superior Sites

1. Mountain along Icicle Creek, Washington
2. Santa Catalina Mountains, Tucson, Arizona-Site A
3. Granite Mountain, Big Delta Region, Alaska-Site A
4. Virgin Mountains, Northwestern Arizona-Site A

Excellent Sites

5. Cleveland Mountain, Skykomish, Washington
6. Virgin Mountains, Northwestern Arizona-Site B
7. Santa Catalina Mountains, Tucson, Arizona-Site B
8. Chugach Mountains, Upper Matanuska Valley, Alaska

Good Sites

9. Granite Mountain, Big Delta Region, Alaska-Site B
10. Mount Mitchell, North Carolina
11. Mount Washington, New Hampshire
12. Whiteface Mountain, New York-Site A
13. Whiteface Mountain, New York-Site B

Although each of the thirteen sites has been thoroughly studied from available geological data, any site finally selected must be adequately explored to ascertain the validity of the paper study. This exploration should include study of surface features, core borings, and man-sized openings, and the use of indirect study methods such as seismic techniques.

Finally, if a future military system has a need for a deep underground support center at depths of 5000 feet below ground surface, this study will serve as a basis for the preliminary investigation of available locations within the continental United States.

A METHOD FOR PRELIMINARY SITE ASSESSMENT

A preliminary assessment emphasizing the important geological aspects of underground cavities located 3000 to 5000 feet below the surface should be made in the review of any inventory of possible sites. The following approach to such an assessment would be applicable and was used as a basis for the study of the sites discussed in Section II (Fig. 2).

Stage 1

Studies would be restricted to delineating all those geographic regions where underground installations are deemed desirable. Within these limits, the most promising areas would be selected on the basis of operational need and systems planning, i.e., access, transportation, communications, type of installation, utility support, and logistics.

Stage 2

This stage would be largely confined to a search of geologic map data and technical data (published and unpublished sources) for sites within areas selected in Stage 1. This study would determine the principal rock type(s) at the surface of sites and supply a rough forecast on depth conditions. The preliminary geologic classification would thus eliminate those sites that have adverse structural features, are confined to areas with known active tectonic stress, or are localized along a seismically active structural zone.

Stage 3

Based on the preliminary assessment of Stage 2, all advantages of geographic setting and engineering attributes inherent to the sites would be evaluated with regard to the general geologic conditions anticipated. This evaluation would eliminate many sites and result in the selection of a small number that offer good potential. Geological conditions as they affect engineering plans can be grouped under the following categories:

a. Surface plant and portal construction, including disposal of waste rock.

b. Excavation of access entries and provision for alternate escape routes in the post-attack period. Surface slopes will be 1:4 or steeper to reduce length of access entries.

c. Excavation of cavity for main installation.

d. Rock support and reinforcement design, decoupling "features" for cavity within cover rock column.

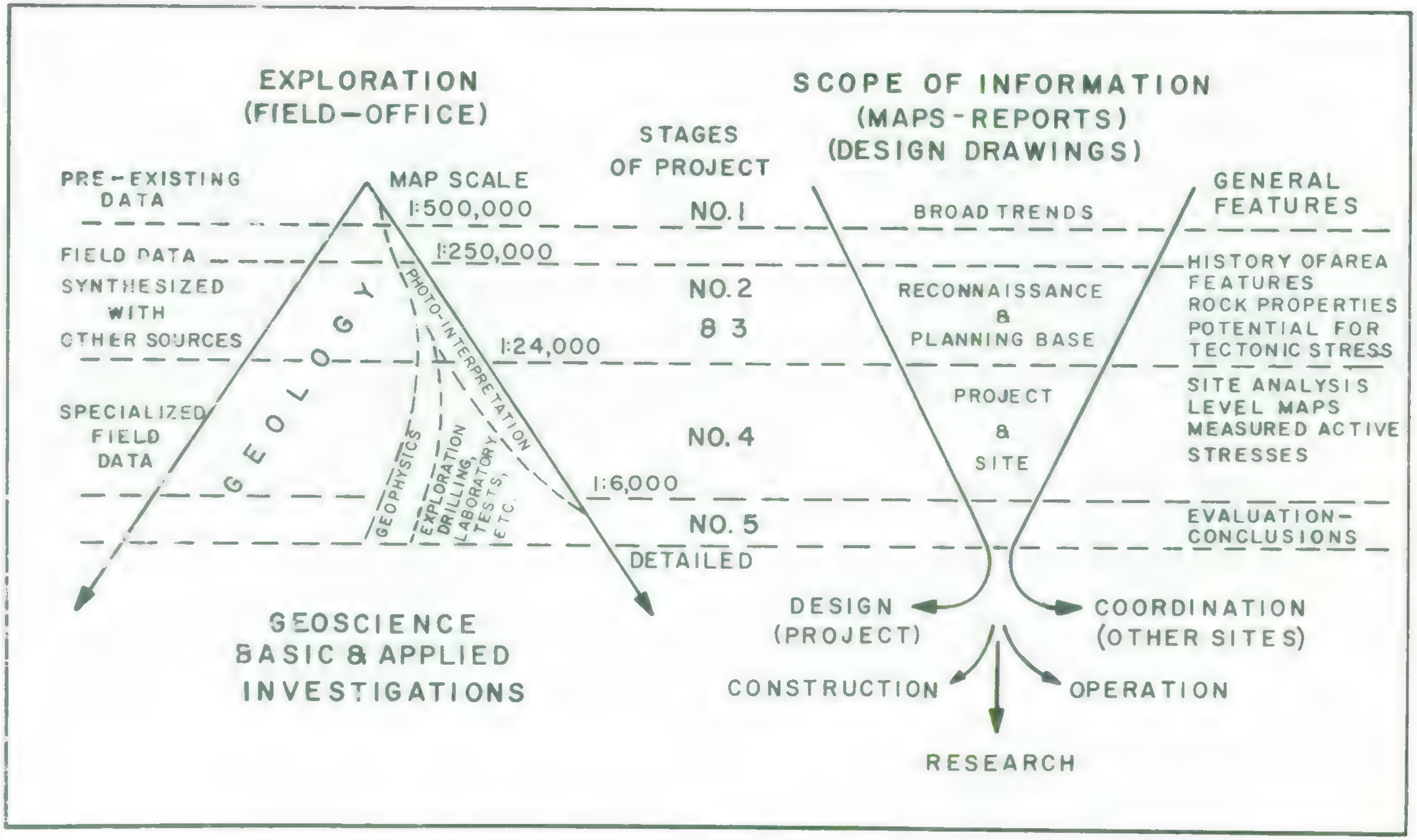

Fig. 2

GEOLOGICAL APPROACH TO THE
ASSESSMENT OF DEEP—UNDERGROUND CAVITIES

e. Operation of the installation involving: ground water occurrence and/or production of a water supply; dissipation of excess heat from equipment; and treatment/disposal of wastes.

Stage 4

A set of level maps would be prepared for the sites selected by Stage 3. Preparation of the level maps would incorporate surface and subsurface geoscience data from all possible sources; maps might be initially constructed on 1000-foot intervals. These plan maps would forecast distribution of the principal rock type(s) and incorporate all pertinent data possible on structural features, ground water, rock properties, seismicity, stress pattern, etc. From this set of level maps, a sufficient number of geologic cross-sections would be prepared to show the anticipated correlation of rock type(s) and geologic features for the site from the surface to below the cavity level. Conceivably, closer interval level maps might be needed, according to geologic conditions. A wide choice of proven methods such as transparent overlays, scale, etc. are available for map preparation. This stage would include inspection of sites and direct field observations to broaden and fill in, where needed, geologic knowledge on the Stage 4 sites.

Stage 5

A study of the surface and level maps and the coordinated geologic cross-sections would serve as a basis for classifying the selected sites of Stage 4 as to their relative merits, i.e., excellent, good, fair, poor, or wholly unsatisfactory. This is the evaluation stage, based on all forms of information gathered in the preceding program.

Stage 6

A set of geologic standards could be prepared to describe the average site conditions of the five categories in Stage 5. Such standards would serve as guidelines for the preliminary assessment of any potential underground site.

For the initial determination of the thirteen potential sites described in Section II, the main factors of Stages 1, 2, 3, and 4 are combined within the geologic cross-section accompanying the description of each site.

GEOLOGIC CONSIDERATIONS FOR DEEP-UNDERGROUND CAVITIES

Obviously, the unusual and dominant adverse features of deep-seated sites should be avoided as they grossly reduce the strength of a rock mass to withstand static, tectonic, and transient. The following describes adverse features common to igneous and metamorphic rock masses, such as at the thirteen sites described in this report. This discussion assumes that a good-quality site rock of strong physical properties occurs at depth, a feature which is shown on the respective geologic cross-sections (Figs. 3 through 15) in Section II.

Adverse Features of Dominant Importance

The sequence of geologic events that has affected a site throughout its history is the most important cause of excessive rock stresses being active within a deep-seated rock mass: e.g., duration, age, intensity, and distribution of stresses causing a recurrence of deformation; amount of cover rock removed by "recent" erosion (unloading and elastic rebound); relationship of three-directional stresses at site level in the rock mass.

While it is well-recognized that tectonic processes produced by mountain-building forces "decay" at a slow rate after the "completion" of the geological event, the rate of "decay" is unknown, and consequently the amount of tectonic stress that remains active today in a mountain range or broadly deformed region may be sizable. In fact, this stress may be several times greater than the static (gravity) stress of the overlying rock column.

Although the importance of a superimposed tectonic stress on the inherent static stress of a mountain range is usually of minor concern for the near-surface sites, at depths of 5000 feet strong tectonic stresses (vertical or horizontal) in young mountain ranges frequently occur. If active, they reduce the safety factor for an underground opening and may even exceed rock strength. Therefore, a reconstruction of the geologic events, type and intensity of rock deformation, and time elapsed since "completion" are necessary data for estimating the percentage or amount of initial tectonic stress that has been dissipated, or, conversely, remains active at any site. From this, the strength capacity of a site rock can be estimated for design needs. Recent tests suggest that part of the active tectonic strain in a mass can be dissipated by subjecting the rock mass to a dynamic-shock stress of a high explosive (HE) or nuclear explosive (NE) explosion. Pilot bores and/or tunnels driven weeks in advance of construction will dissipate some of the active strain.

The occurrence of the following secondary structural features reduces the mass strength of a rock mass: closely-spaced faults; wide fault or shear zones; tight folds and highly-deformed, metamorphic beds; or a closely-spaced pattern of persistent joint planes; and a parallelism of primary or secondary planar structures.

Closely associated with these mega-structures are less important but potentially adverse features such as bedding plane faults, frequent caverns, and pronounced sheet joints (most common near-surface, or within cover rocks).

The occurrence of excessive rock temperatures, although uncommon, is an important possibility.

Under certain conditions of geologic history where magma is cooling at shallow depths, the geothermal gradient may be 5 to 60 times normal (1 degree Fahrenheit increase for each 60 to 140 feet of rock depth). Excessive wall rock temperatures contribute heat to the underground installation that must be dissipated; and, frequently, areas of high geothermal temperatures have associated hot waters and some steam.

The seismicity potential of a site, and particularly the expected intensity (damage factor) for the rocks of proposed site must be ascertained.

Other Adverse Features

If the rock mass possesses many structural features that have fractured the rock extensively, very likely one or more of the following adverse conditions will occur:

Zones of strongly-weathered (rotton) or hydrothermally-altered (chemical) rock, and the abundance of soft alteration minerals and clay seams along the numerous fracture planes. This condition is particularly important within 2500 feet of the surface; it is less important below this depth, except in major fault zones where it may exist even at 5000 feet.

The "impermeable" rocks may possess a skeleton ground water system within 1 to 3000 feet of the surface, dependent upon the structural features. These conditions of ground water are uncommon at depths of 5000 feet in massive rock.

If the fracture system is extensive and interconnected, the ground water system may exist even at depths of 5000 feet and may then warrant serious evaluation. Rocks that possess large quantities of water within 1 to 3000 feet of the

surface (or deeper) may be dense and "impermeable" at 5000 feet. If so, such a reduction in porosity is the direct function of the filling of any natural void by mineral matter precipitated (through time) from the circulating ground water and/or the tightness of all fractures due to stresses inherent at depth.

Sites in moderate to steep-dipping bedded or foliated rock are unsuited to the design of some cross-sectional shapes if this feature is a controlling factor.

Bedded rocks are not considered for sites at depths of 5000 feet in this preliminary discussion. However, some foliated or tectonite rocks are strong and react similarly to the massive igneous rocks such as the granites. Consequently, all rocks with planar structures should not be rejected solely on the basis of this property, but should be evaluated as to strength and physical characteristics consistent with design needs.

Toxic gases may occur in sedimentary rocks, but they are unlikely in igneous and metamorphic rock masses unless special geothermal conditions exist.

Suitability of Rock Types

Granites

The general consensus based on experience with underground excavation is that igneous rocks such as the granites are the best rocks for large-scale underground cavities at depths of 5000 feet. Features of granites that substantiate this selection are: a high compressive strength; usually a minimum fracture system; usually a minimum of ground water; and usually a strong durable rock in essentially fresh condition.

The compressive strength of good-quality, homogeneous granites, equivalent porphyritic rocks, and diabase will range between 15,000 and 40,000 pounds per square inch. The fine-grained rock types are in the 25,000 to 40,000 psi, range while coarse-grained varieties are in the 15,000 to 25,000 psi range. The static (gravity) stress in a mass of such rocks increases at the rate of approximately 1.1 psi for each foot of the overlying rock column.

At a depth of 5000 feet, the approximate vertical stress inherent to the site rock in granites is 5500 psi. Although under the average conditions of ancient mountain areas, the horizontal and lateral stresses at 5000 feet are less than the vertical stress (1/3 - 1/2 of vertical), the actual stress distribution at depths of 3000 to

5000 feet may vary over wide limits, depending on the geologic history of the rock mass (mountain range and ancient deformation), and the proximity of the deep site to a free vertical boundary.

Our recent realization that active tectonic stresses are present at depths of 3000 to 5000 feet and below in young mountain ranges requires that special consideration be given to assessing the potential for tectonic stress within an area. Sites located in young or rejuvinated mountain areas where some amount of tectonic stress could be active have been noted on the geologic cross-sections of this report.

Recent development of methods for the measurement of actual state of stress in underground openings points out the imbalance between the hydrostatic theory (stresses equal in all three directions at depth) and the theory of stress distribution based on Poisson's ratio (horizontal and lateral stress approximately one-third vertical stress). The recent studies show that the horizontal and/or lateral stress may be equal to or as much as 3.5 times greater than the vertical stress. The cause of the relatively high horizontal and/or lateral stress is undoubtedly a function of the geologic history, with the high compressive stresses being due to partly decayed tectonic forces of the past, or in some cases to forces that are currently active (Hast, 1958;[3] Moyo, 1960;[4] and Serafim, 1961).[5] These studies confirm the note of caution concerning unrelieved tectonic stress that may be active at an underground site, and furthermore confirm the correlation of potential tectonic stress with the series of past geologic events (history site rock).

Other Suitable Rock

Other types of rocks that possess good physical characteristics for deep underground cavities are:

a. metamorphic rocks such as gneiss phyllite, massive quartzite, amphibolite, and some greenstones;

b. volcanic rocks such as massive rhyolite, latite, dacite, andesite, basalt and porphyritic variations (particularly porphyries or a thick series of ancient andesite or basalt that has been healed and strengthened by some deformation and age).

The latter type does not include an abundance of porous interbeds of ash, breccia, and cinders, but is a dense thick series that is massive in its gross properties.

The physical characteristics of the above group are somewhat similar to those reviewed for the granites, i.e., comparable physical strength, a lack of inherent ground water, fresh rock conditions, and the ability to stand open in large underground openings.

The compressive strength of good quality, homogeneous metamorphic and volcanic rocks given above is comparable to the fine-grained granites (25,000 to 40,000-psi). Some varieties, due to their inherent structures and mineral composition, are weaker and in the 12,000 to 25,000-psi range (still other varieties are even lower in strength).

EXPLORATION OF SITES

Any proposed site that is considered for the design of a deep underground cavity should be adequately explored prior to final design. This geologic exploration should include a study of surface features, core borings, and man-sized openings, and the use of indirect methods to study subsurface depths below the tunnel and cavity level.

The initial step should be the preparation of a geologic map of the site and vicinity (scale 1 inch = 500 feet). Particular attention should be given to determining the physical properties of all rock units and to locating and plotting the structural features and their projection to the proposed tunnel and cavity areas.

Core borings, which are the most efficient method of exploration, provide data in proportion to the diameter of the drill hole. An NX, or 2-1/8-in. core, is the smallest hole size which can be used in the exploration of a deep site. A more effective means of exploring the subsurface conditions employs a man-sized opening 6 feet in diameter. The ideal way of utilizing this technique is to excavate a pilot bore along the access tunnel alignment and continue the bore into the cavity area. A second method is to sink a shaft into the cavity area; although this method requires driving a much shorter opening, it will not provide as much information and may cost almost as much as the pilot tunnel. The man-sized opening offers the best opportunity to evaluate all the structural features in the site rock and to measure its *in situ* strength including its stress-strain characteristics for the proposed openings.

A TV-camera is now available for viewing the interior of core holes. This is a supplementary means of examining areas of poor core recovery to ascertain *in situ* conditions.

Geophysical methods, particularly the seismic survey technique, can be used to measure indirectly the elastic moduli of site rock as well as to determine the general features of the mass. The measurement of resistivity can be used to delineate structural zones and rock contacts and indirectly provides a measure of the rock temperatures.

Representative specimens of site rock should be tested in the laboratory for the usual strength and shear properties consistent with design needs.

On the basis of surface and subsurface exploration data a level map of the site should be prepared along the proposed access tunnel

and throughout the cavity area. This plan map should include the distribution of all rock units, the anticipated location of all rock contacts and structural features to be encountered, the estimated ground water conditions, and it should delineate all areas that are expected to require reinforcing supports. As construction progresses, the level map should be modified on the basis of as-encountered conditions. In this manner, conditions that were not forecast from the pre-construction exploration program can be projected ahead of the tunnel excavation and thereby serve as an up-to-date assessment of conditions anticipated within the site.

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SECTION II

This section of the report illustrates the value of using a systematic approach to the geologic assessment of a particular site. Each of the thirteen sites discussed here was selected and evaluated in the manner described in Section I. The sites selected were strategically located in five general geographical areas of the United States, including Alaska. The selection was based on:

1. the anticipated occurrence of favorable sub-surface geologic conditions at depths of 5000 feet;

2. satisfactory topography;

3. regional and areal location; and

4. accessibility for military purposes.

A survey was made of published data for each site and the available material has been referenced at the end of the report. The dominant geologic conditions at each site are described and the sub-surface relationships interpreted and forecast on a geologic cross-section included with each study. The cross-section is along a possible access tunnel alignment to depths at least 5000 feet below any point on the surface. The sites selected were limited to igneous rocks such as granites or metamorphic rocks of gneiss at the potential cavity depth; furthermore, granite or gneiss occur for at least 1000 feet above the proposed cavity level.

All thirteen sites are of extreme relief due to steep slopes that rise above the surrounding countryside. The steep-slope sites consist of a "core" of igneous or metamorphic rock that in some instances is overlain by a cover of sedimentary or metamorphic rock units. The relationship of the potential deep cavity to the surrounding countryside is shown on the geologic cross-section. The areal location of the site is shown on a small locality insert map which includes the principal roads, railroads, rivers, mountain peaks, towns, airports, and a generalized distribution of the rock types and structural features within several miles of the site.

The selected sites provide at least 5000 feet of cover by the excavation of a horizontally oriented access tunnel on an incline of not more than 5° 43' (10%). Portals of the postulated tunnels are at low elevations and all are within a short distance of major highways or railroads.

NORTHEASTERN UNITED STATES

Mount Washington, New Hampshire — Site A
(Latitude 44° 16', Longitude 71° 18')

Geographic Location and Accessibility

A deep underground site is proposed beneath Mt. Washington, New Hampshire, with an access tunnel trending N 70° W from a portal located at Pinkham Notch to beyond the peak. The areal setting of the site is shown on the Locality Map in Fig. 3.

Alternate portal locations for this site are 500 and 1000 feet west of the all-weather Highway 16. The Boston and Main Railroad lies 11 miles north at Gorham, as well as 18 miles away at Berlin, New Hampshire. Glen is 13 miles south of the site.

Site Topography

The area of Mt. Washington is rugged, with steep terrain due to the numerous glacial-scoured ravines and canyons. The barren rock surface rises on a steep grade from Pinkham Notch at an elevation of 2032 feet, to the crest of Mt. Washington, 6288 feet (see Fig. 3). Topography and features of the area surrounding Mt. Washington are given on U.S. Geological Survey Quadrangle map, Mt. Washington, New Hampshire, 1938 edition, with a contour interval of 20 feet, at a scale of 1:62,500.

Small lakes dot the flanks of Mt. Washington, and many perennial streams headwater on its upper slopes.

The access tunnel alignment follows beneath a ridge on the lower eastern flank of the mountain and parallels the Cutler River canyon throughout the mid-slope section. Several sharp ravines and glacial-scoured canyons traverse the access tunnel alignment, reducing the thickness of rock cover. A cover of 5000 feet is not attained until the access tunnel is nearly beneath Mr. Washington peak, as shown in Fig. 3.

If a larger subsurface area with 5000 feet of cover is desired, an alternate access tunnel, located 400 feet deeper, could be driven. If a thicker cover of rock is desired within 6000 feet of the portal, a "dog-leg" alignment for the tunnel will increase the cover (and also move it from beneath the Cutler River on mid-slope) by trending N 82° W from the portal for 6200 feet, thence N 60° W beneath the mountain.

Geologic Setting

This site is located to the north and east of an extensively deformed, faulted, and complex series of rocks in north central New Hampshire. The vicinity of Mt. Washington is a broadly folded area; the three principal rock types are continuous in their subsurface occurrence, as shown in Fig. 3. Areal distribution is shown on the Locality Map in Fig. 3. A fourth rock unit, schist and injection gneiss, occurs as a thin band between the extensive gneiss and the surface series of schist and quartzite.

Rock Units of Site

Schist and Quartzite (interbedded). A wide area of interbedded schist bands and quartzite beds caps Mt. Washington and extends northward to Gorham. This schist and quartzite series is approximately 1500 feet thick directly beneath Mt. Washington and is interpreted to be some 3000 feet thick in the section midway between Mt. Washington and Pinkham Notch. The principal physical features of this rock unit are given in Fig. 3, both for the near-surface zone (500 to 800 feet) and at depths below (up to 3000 feet) where encountered along the access tunnel alignments.

Schist and Injection Gneiss. Underlying the schist and quartzite unit is a thin band of schist and injection gneiss some 150 to 200 feet thick. This band is distorted, folded, and in part shattered as a result of its origin as an injection along the gneiss and schist-quartzite boundary. In composition the rock unit is gradational from the overlying schist-quartzite to the underlying gneiss.

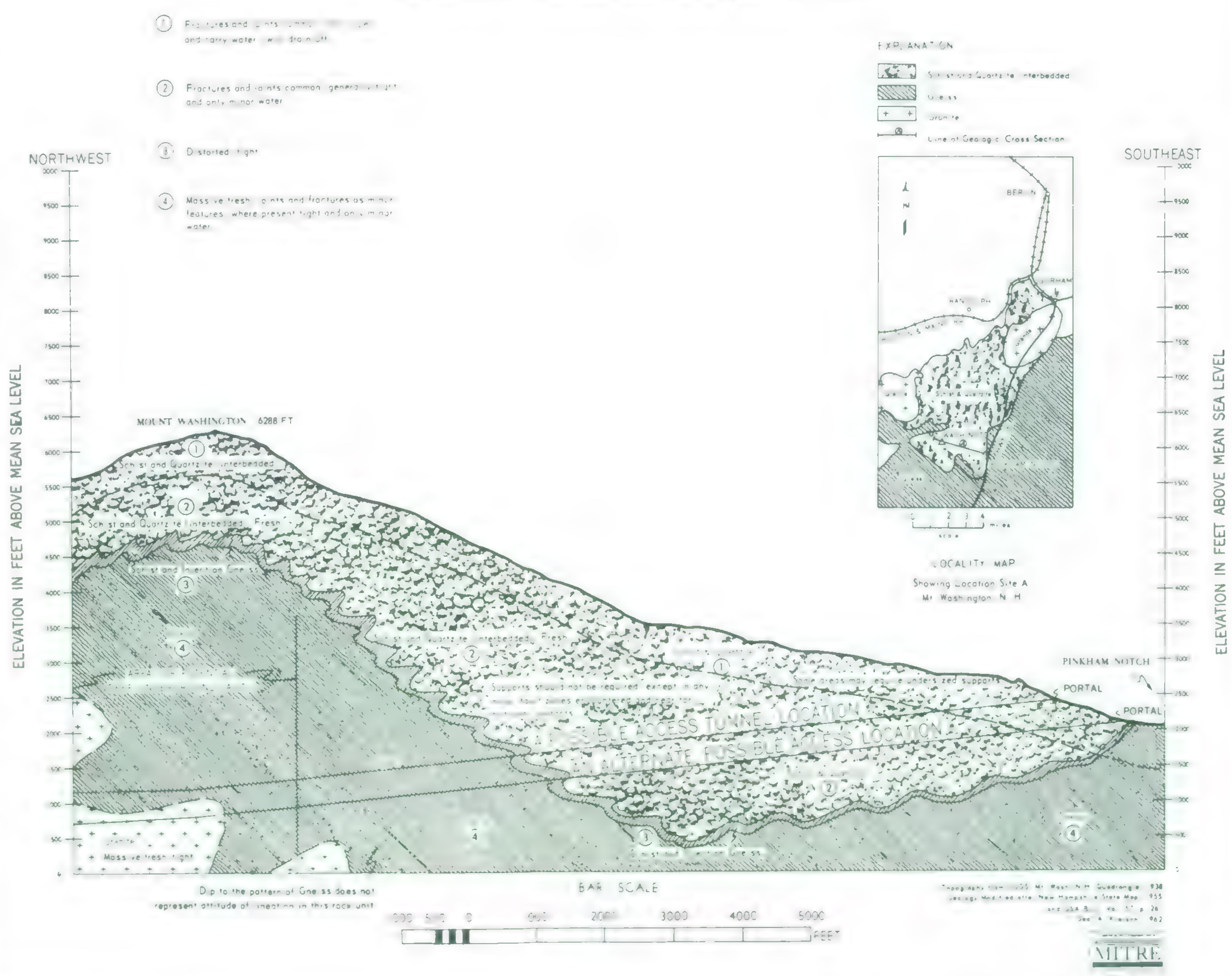
Gneiss. A body of massive gneiss occurs everywhere beneath the band of schist and injection gneiss. This coarse-grained rock consists primarily of quartz and orthoclase minerals with alternating bands of mica. Its physical properties are similar to those of a granite. By correlation of surface and subsurface data, the gneiss unit is estimated to be at least 3500 feet thick; its lower boundary grades into granite (as plotted on Fig. 3).

Granite. West of Mt. Washington, granite crops out; this rock body extends beneath the site, occurring at a depth of some 5000 feet. This depth is not precise, as the granite-gneiss contact is gradational and undoubtedly consists of intermixed gneiss and granite for several hundred feet. Physical properties of the gradational gneiss-granite and the granite unit itself are expected to be very similar. The irregular and contorted gradational contact of the granite is partly due to the folding which uplifted the Mt. Washington area.

Fig. 3

MOUNT WASHINGTON, NEW HAMPSHIRE Site A

Looking Northeastward along Geologic Cross-Section from Pinkham Notch to Mt. Washington
North 70°00′ West in Lat. 44°16′, Long. 71°18′



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Structural Features

No major structural features have been reported in the vicinity of Mt. Washington and Site A. The geologic map of New Hampshire (1955) shows no strong fault zones or structural trends that traverse the proposed Site A. The principal structural feature is the broad areal folding (the anticline of Mt. Washington, and the syncline of the portal area) as shown in Fig. 3.

The common structural features at Site A are relatively small-scale. Undoubtedly, numerous small fault zones are scattered throughout the folded mountain mass. Joints and fractures are abundant throughout the schist-quartzite unit and the gneiss unit where exposed on the barren slopes. The schist is characterized by parallel bands or schistosity.

The structural conditions anticipated within the upper 500-foot to 1000-foot layer of schist and quartzite are shown in Fig. 3. Undoubtedly, many of the inherent fractures and joints will be open and carry quantities of water. This is particularly true in the vicinity of the lakes and numerous streams such as the Cutler River. With depth, however, these fractures tighten, are not inter-connected, and occur increasingly farther apart. Thus, any water intercepted by the access tunnel construction should be limited in quantity (restricted to open joints of near-surface zone) and, therefore, the inflow will drain off within a reasonable time.

At depths greater than 500 to 1000 feet, the underlying rock units will probably be in a: relatively fresh condition; the minor joints and fractures should be tight, and contain ground water only in small quantities.

Advantages of Proposed Tunnel Alignment

The alignment for Site A was chosen to extend from Pinkham Notch to beneath Mt. Washington (N 70° W) for three reasons:

a. The access to the portal via Highway 16 is ideal.

b. Alternative portal locations on the southern flank of Mt. Washington would be inaccessible as no roads are within several miles.

c. Due to surface topography, any tunnel alignment on the south, west, and particularly northern flanks of Mt. Washington would be longer than the proposed Site A.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The principal rock conditions along the proposed alignment are described in Fig. 3. Reinforcing and supports for underground openings may be required within the first 500 to 1000 feet from the portal, where the tunnel traverses the interbedded schist bands and quartzite beds. Supports may also be needed for a distance on either side of the formational contacts, such as the schist-quartzite contact with the schist and injection gneiss, and the contact of the latter with the gneiss unit. Also, if any major fault zones are encountered (none are shown on the existing maps), the rock within the fault zone may be broken, crushed, deteriorated and weak, and may therefore require supports.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

Figure 3 shows two possible alignments for an access tunnel beneath Mt. Washington. Both alignments are expected to encounter the gradational rock (granite-gneiss) in the vicinity of the deep cavity and at depths of 5000 feet of cover. No unusual conditions are anticipated due to the gradation of the gneiss unit to gneiss-granite and the granite unit as shown within the area of the potential underground cavity. All three rock types are similar in their engineering properties: they are massive, strong, and in a fresh condition; any joints and fractures present in these rocks should be widely-spaced, tight, and of minor influence on tunneling conditions.

Supports should not be required along an average-sized tunnel, except in any fault zones encountered. Requirements for supports and reinforcement within the cavity will be directly related to the size of the underground opening constructed.

Dominant Favorable Features of Deep-Underground Site

Site A beneath Mt. Washington includes the following favorable conditions for a deep-underground site:

a. The cover rock overlying the proposed cavity area consists of three distinct and "layered" rock units, schist and quartzite (interbedded), schist and injection gneiss, and gneiss. This condition of "layering" of contrasting rock types within the cover results in partial reflection of the pressure pulse due to large scale surface or near surface explosions. Only a partial transfer of energy is effected across each contrasting rock boundary.[3]

b. The gneiss-granite host for the deep cavity is a massive, strong, high-quality rock.

c. The region of Site A was deformed in very ancient geologic time (Paleozoic), and since then has been rather stable. Consequently, the tectonic stresses associated with the ancient mountain-building and deformation of these rocks have largely or fully decayed. The long intervening time of approximately 185 million years since mountain-building has allowed the Mt. Washington mass to de-stress, and consequently, only static stresses should be active at the depths of the proposed cavity. The region is considered to be seismically inactive.

Adverse Features of Deep-Underground Site

A depth of cover in excess of 5000 feet is difficult to obtain beneath the Mt. Washington site due to the elevation of the Peabody River channel in the vicinity of Pinkham Notch. A portal located elsewhere to attain a greater cover would be inaccessible and would require a much longer access tunnel.

The usual tunneling precautions will be required consistent with accepted practice of deep-underground excavation.

Whiteface Mountain, Near Lake Placid, New York - Site A
(Latitude 44° 22', Longitude 73° 47')

Geographic Location and Accessibility

Two access sites are proposed to a deep-underground cavity beneath Whiteface Mountain, New York. Site A is located directly east of Highway 86 at a point some 10 miles north of Lake Placid and two miles south of Wilmington, New York, as shown in Fig. 4. The portal is 3000 feet west of the West Branch of the Ausable River and one mile from Highway 86. This alignment trends due west beneath Whiteface Mountain.

Site Topography

Whiteface Mountain is the principal peak of this region, rising to an elevation of 4867 feet. The topography is steep in the area immediately surrounding the peak and flattens to gently sloping terrain around the flanks of the mountain. The surface consists of ridges and valleys controlled by the natural joints in the rocks which have influenced the location of the small tributary streams. The access tunnel alignment crosses beneath two small tributaries of the West Ausable River, and in each case, small canyons are carved in the

surface rocks. Frequently, the streams follow a rock contact, as demonstrated in Fig. 2 for the canyon between the granitic rocks and the anorthosite. The topography and features of the area surrounding Whiteface Mountain are given on U.S. Geological Survey Quadrangle Sheet, Lake Placid, 1953 edition, with a contour interval of 20 feet, at a scale of 1:62,500.

A cover of 5000 feet is not attained until the access tunnel is beneath Whiteface Park. Consequently, this site offers a limited amount of subsurface area with 5000 or more feet of cover. Site B (see Fig. 5) offers even less area of thick cover.

The Whiteface Mountain Authority, State of New York, is preparing a detailed topographic map of the area (6 square miles) at a scale of 1:4800 and a contour interval of 10 feet. Recent aerial photographs at a scale of 1:20,000 are available. The Authority, through Atmospheric Sciences Research Center, State University of New York, plans on sponsoring a detailed geological study of the area.

Geologic Setting

This site is located on the eastern flank of Whiteface Mountain in an area of several rock types which grade into each other. Grossly, they appear similar in composition and physical properties. Whiteface Mountain consists primarily of anorthosite (Whiteface) as a core which extends to depths below the proposed access tunnel level. On the margins of the anorthosite core, similar rocks occur as bands and lenses, as shown on the Locality Map in Fig. 4. These lenses and tongues are gradational in their composition, so that the location of the boundaries shown on the geologic cross-section is only approximate.

Rock Units of Site

Anorthosite (Whiteface). The main core of Whiteface Mountain consists of anorthosite that extends to depths in excess of 5000 feet; this Whiteface anorthosite is believed to be connected at depth with similar anorthosite that crops out near the portal. (However, this connection is not shown in Fig. 4 because no subsurface data are available between the two outcrops.) Since anorthosite is an intrusive rock, a connection is very probable, implying that the lenses and tongues of granitic rock, gneiss, and syenite which occur between the two anorthosite outcrops are cut off at depth by the intrusive anorthosite. While this intrusive contact is expected to be below the proposed access tunnel level, no unusual difficulties are foreseen even if the contact is at or above the tunnel level, because the physical properties of all site rocks are similar.

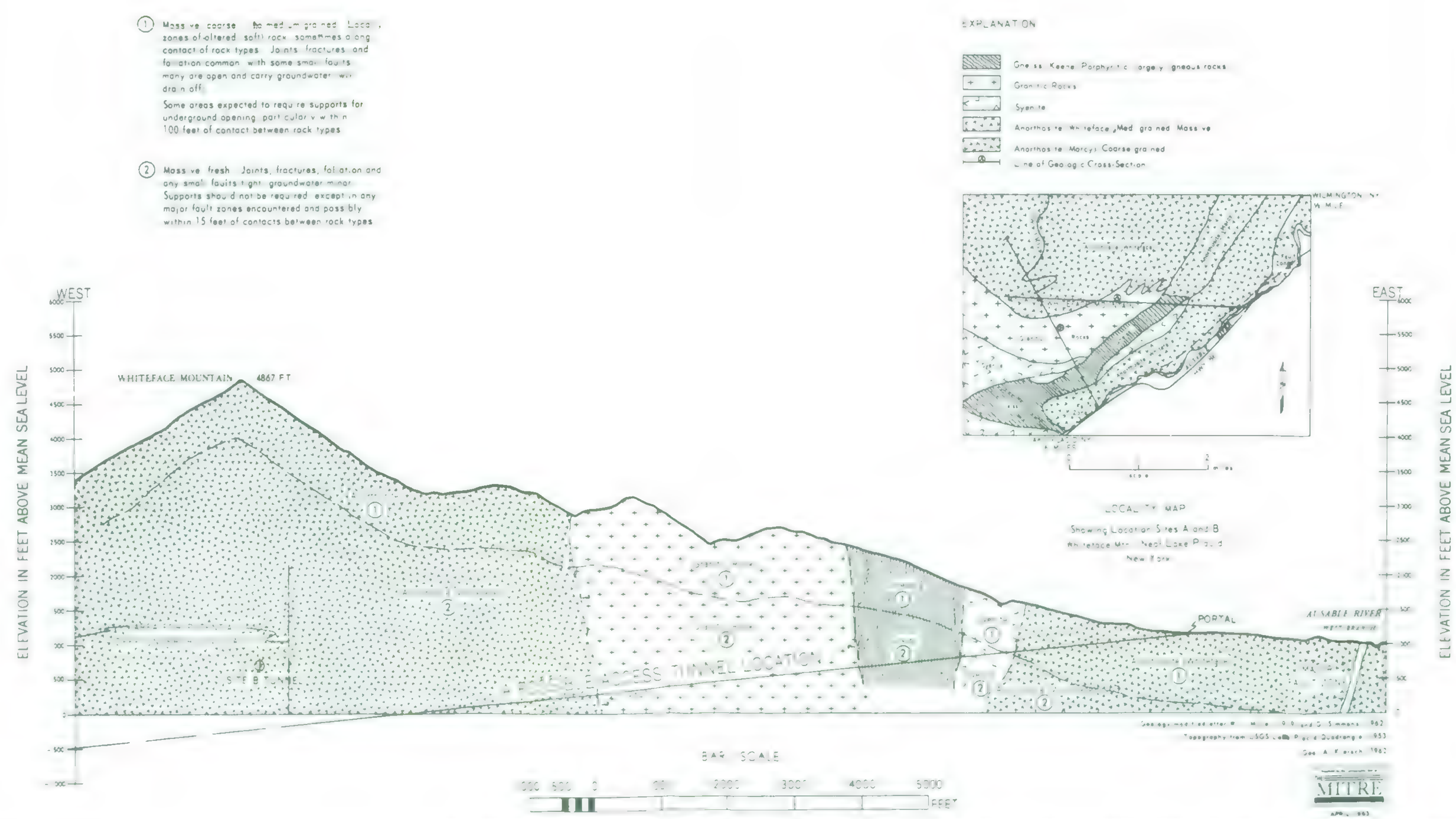
The anorthosite, with characteristics similar to that of a coarse-grained granite, is light to dark green and consists of individual

Fig. 4

WHITEFACE MOUNTAIN, NEAR LAKE PLACID, NEW YORK Site A

Looking North along West-East Geologic Cross-Section

Lat. 44°22′ , Long. 73°47′



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crystals up to six inches in length that frequently possess a rude alignment. Its strength and physical properties are similar to those of a granite.

Granitic Rocks. The wedge-shaped body of granitic rock shown in Fig. 4 grades into the anorthosite on the west and north, as well as in depth, while it grades into gneiss on the east. This ancient granite was intruded by the younger anorthosite. The gradational contacts are expected to be tightly welded and not those formed by a fault or intrusive breccia contact. Part of the granitic body is granite pegmatite and felsitic porphyry composed of large crystals, both of which are common differentiates of granitic rock in the area. The physical properties of all the "granites" are similar.

Gneiss. A small, wedge-shaped mass of gneiss about 1000 feet wide occurs on the eastern margin of the granitic rocks, as shown in Fig. 4. This gneiss is reported to be crushed or broken in many areas. As no field examination was undertaken prior to the preparation of this preliminary report, particular attention should be given to the gneiss and its physical properties in the vicinity of the access tunnel alignment. This rock possesses a strong lineation and parallel weakness planes in parts that consist of biotite granite-gneiss and pyroxene-bearing syenite gneiss. The latter rock includes lenses and bodies of metasediments, metaquartzite, and biotite-quartz-oligoclase gneiss. This variation in composition demonstrates a varied origin for these rocks. The gneiss grades into syenite on its eastern margin. This rock unit may possess a wide variation in physical properties, ranging from excellent to weak, and warrants investigation.

Syenite. A small wedge of syenite less than 1000 feet wide and apparently pinching out at a depth of some 2000 feet occurs on the eastern margin of the gneiss and is bounded on the east by anorthosite. This syenite body is similar in its physical properties to the granitic rocks. Contacts between the anorthosite and syenite and the syenite and gneiss are expected to be gradational and tight, and should create no special problems when traversed by an access tunnel.

Structural Features of Site

Several geologic investigations of the Whiteface Mountain area (Miller, 1919;[9] New York State Geologic Map, 1962[10]), have shown no major structural features within the limits of Site A. A major fault trending northeast occurs along the West Branch of the Ausable River. A second major fault zone trending parallel to the Ausable River fault traverses the area four miles west of Whiteface Mountain. Some three miles north of Whiteface Mountain a zone of similar magnitude trends nearly east-west between the two parallel faults.

Site A is located within a large regional block which is bounded by faults on three sides; the site is not disturbed by any major structural zones. The rock units are somewhat deformed due to igneous intrusion and possess the lineation patterns typical of metamorphics (gneiss) and ancient rocks such as the anorthosite and granitics. This lineation is partly shown on the Locality Map by the trend of the tongues and lenses of granitic rocks — gneiss, syenite, and anorthosite — that occur on the southern and eastern margins of Whiteface Mountain.

None of the structural conditions at this site appear to be of major importance in selecting the location of an access tunnel and area for a deep-underground cavity.

The contact zone between each rock type traversed by the alignment may be fractured, constituting a structural feature which requires support in a tunnel. Evidence indicates, however, that the contacts are tight and are not structural features of broken rock.

The body of gneiss crosscut by the access tunnel may be crushed and broken, requiring special attention and supports in the tunnel. If present, the crushing and weakness would be due to the schistosity and banding of this rock.

The area is considered to be seismically inactive.

<u>Advantages of Proposed Tunnel Alignment</u>

The alignment for Site A offers three major advantages:

a. It is easily accessible and its portal is located within one mile of Highway 86.

b. Sufficient topographic relief is available to attain a cover thickness of 5000 feet within a reasonable length of access tunnel.

c. It has an alignment which traverses the best rock conditions of the peak.

<u>Rock Conditions Anticipated Along Proposed Tunnel Alignment</u>

The general condition of all rock types within the near-surface zone of 500 to 1000 feet is given in Fig. 4. This zone is affected by weathering and surface conditions; joints and fractures are abundant, weathering has deteriorated the rocks to shallow depths and along fracture planes, and ground water occurs as a skeleton system within the joints and interconnected openings. All rocks concerned

(anorthosite, granitic, gneiss, and syenite) possess similar near-surface conditions. This is further emphasized by the rather even topography and rock contacts of this site.

The possible access tunnel location shown in Fig. 4 requires over 12,000 feet of inclined (5° 40') tunneling to attain a cover rock of 4500 feet. The access tunnel attains a cover of 5000 feet farther on beneath Whiteface Peak at a point 13,500 feet from the portal. Support and reinforcement will be required in the vicinity of the portal and perhaps to depths of 500 feet or more of cover. The tunnel alignment cuts across the syenite-anorthosite contact where cover depth is some 500 feet. This contact may carry excessive water due to possible strong fracturing, and, in general, may require special attention and support.

The syenite-gneiss contact will be encountered at a point where the cover is some 1000 feet thick. Under these conditions, this contact may create problems similar to those found in the syenite-anorthosite contact. The foliation and parallel fractures of the gneiss are likely to occur at a steep angle, perpendicular to the tunnel alignment. As a result, these vertical fractures may cause an overbreak with blocks of gneiss spall from the roof of the opening. The gneiss may require special attention, both for safety and tunneling design, but conditions will not be treacherous.

The gneiss-granitic rock contact would be encountered at a point some 4400 feet from the portal with a cover of at least 1700 feet. This contact presents fewer possible difficulties than the two contacts encountered closer to the portal. The granitic-anorthosite contact would be encountered at a point where the cover is in excess of 2500 feet; no particular difficulties or unusual conditions are anticipated. Since both of these contacts are intrusive, they are expected to be tightly welded or gradational and without serious structural defects. Except as noted, supports should not be required along an average-sized tunnel. Requirements for supports and reinforcement within the cavity will be directly related to the size of the underground openings constructed.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

The rock within the vicinity of the proposed deep-underground cavity at Site A (4500 to 5000 feet of cover) is a massive, coarse-grained anorthosite. This rock, whose physical properties are similar to those of granite, is expected to be a strong, durable, massive rock, with engineering properties similar to those of good-quality granite. Joints and fractures, where present, should

be widely-spaced, tight, and of only minor influence on the design and tunneling conditions. No appreciable quantities of ground water are expected at the level of the cavity.

Dominant Favorable Features of Deep-Underground Site

Site A offers two critical advantages over Site B at Whiteface Mountain in a comparison of the two alignments:

a. The Site A access tunnel is 500 feet lower at maximum depth than the access tunnel for Site B (see relative plots in Figs. 4 and 5).

b. Difficulties might arise at Site B because the proposed cavity area lies close to the contact between the granitic rocks and the main mass of anorthosite. If this contact is fractured rather than gradational, this rock distribution would affect design and construction.

The region of Site A was deformed in very ancient geologic time, and since then has been rather stable. Consequently, the tectonic stresses associated with the uplift and deformation of these rocks have largely or fully decayed. Only static stresses should be active at depths of the proposed cavity. The region is considered to be seismically inactive.

Adverse Features of Deep-Underground Site

A large subsurface area with at least 5000 feet of cover rock is difficult to attain at this site. While the maximum cover with a reasonable access tunnel is realized by the Site A alignment, this proposed entry limits the total area with 5000 feet of cover, as shown by the subsurface plots in Figs. 4 and 5).

No portal site could be located which would allow a greater subsurface area with 5000 feet of cover, which had a reasonable length of access tunnel.

A steep incline or vertical shaft could be constructed near the portal of either Site A or Site B and thereby drop up to 500 feet in depth before driving the inclined access. Using this method, the area of maximum cover rock could be extended beneath Whiteface Mountain. No logical portal sites occur on the west, south, or north margins of Whiteface Mountain which would increase the thickness of cover rock for a deep site. Portal sites along the canyon of the West Branch of the Ausable River offer the lowest elevations in the immediate vicinity.

The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

Whiteface Mountain, near Lake Placid, New York - Site B
(Latitude 44° 22', Longitude 73° 47')

Geographic Location and Accessibility

An alternate deep-underground site is proposed beneath Whiteface Mountain, New York, with the portal located some 2 1/2 miles southwest of Site A. The portal of Site B is located adjacent to Highway 86 at a point some seven miles northeast of Lake Placid, on Highway 86. The areal setting of the site is shown on the Locality Map in Fig. 5.

Site B is located within 1000 feet west of Highway 86 on the west bank of the West Branch of the Ausable River (see Fig. 5) at a portal elevation of some 1480 feet.

Site Topography

The area of Whiteface Mountain is steep terrain, as described for Site A. The topography along alignment B rises abruptly from a portal elevation of approximately 1480 feet to Whiteface Peak at 4867 feet in a distance of 9500 feet. The topographic area surrounding Whiteface Mountain is given on U. S. Geological Survey Quadrangle map, Lake Placid, New York, 1953 edition, with a contour interval of 20 feet, and at a scale of 1:62,500.

This alternate site alignment offers a shorter access tunnel to the area directly beneath Whiteface Mountain than does Site A. An access tunnel of approximately 8500 feet gives a cover rock of 4400 feet beneath the mountain peak.

Site A tunnel location throughout the subsurface area of the potential cavity is some 500 feet beneath the alignment of the alternate Site B, as shown in Fig. 5.

The Whiteface Mountain Authority, State of New York, is preparing a detailed topographic map of the area (6 square miles) at a scale of 1:4800 and a contour interval of 10 feet. Recent aerial photographs at a scale of 1:20,000 are available. The Authority, through Atmospheric Sciences Research Center, State University of New York, Albany, plans on sponsoring a detailed geological study of the area.

Geologic Setting

The site is located on the southeastern flank of Whiteface Mountain in an area of several rock types which grade into each other. Grossly, they appear similar in composition and physical properties. Whiteface Mountain consists of anorthosite (Whiteface) and granitic rocks as a central mass. The anorthosite extends to depths below the proposed access tunnel level. On the margins of the granitic rocks, lenses and tongues of syenite and gneiss occur as shown on the Locality Map in Fig. 5. These lenses and tongues are gradational in their composition, so that the location of the boundaries shown on the geologic cross-section is only approximate.

Rock Units of Site

Anorthosite (Whiteface). The main core of Whiteface Mountain consists of anorthosite that extends to depths in excess of 5000 feet. The physical properties and conditions of the anorthosite throughout the area are described in detail in the previous section on Site A. The Site B access alignment varies from the Site A alignment principally with respect to the position of the contact between granitic rocks and the anorthosite beneath Whiteface Peak. The location and gradational features of this contact are shown in Fig. 5.

The main anorthosite mass beneath Whiteface Peak is believed to be connected at depth with similar anorthosite that crops out in the vicinity of the portal, Site B. (However, this connection is not shown in Fig. 5 because subsurface data confirming this are not available.) Since the anorthosite is an intrusive rock, a connection is very probable, implying that the lenses and wedge-shaped masses of granitic rocks, syenite, and gneiss are cut off at depth by the intrusive anorthosite.

Granitic Rocks. The wedge-shaped body of granitic rock shown in Fig. 5 grades into the anorthosite on the west, north, and in depth, and into syenite on the east. This ancient granite was intruded by the younger anorthosite. The conditions of the contacts and the physical properties of this rock are described under Site A.

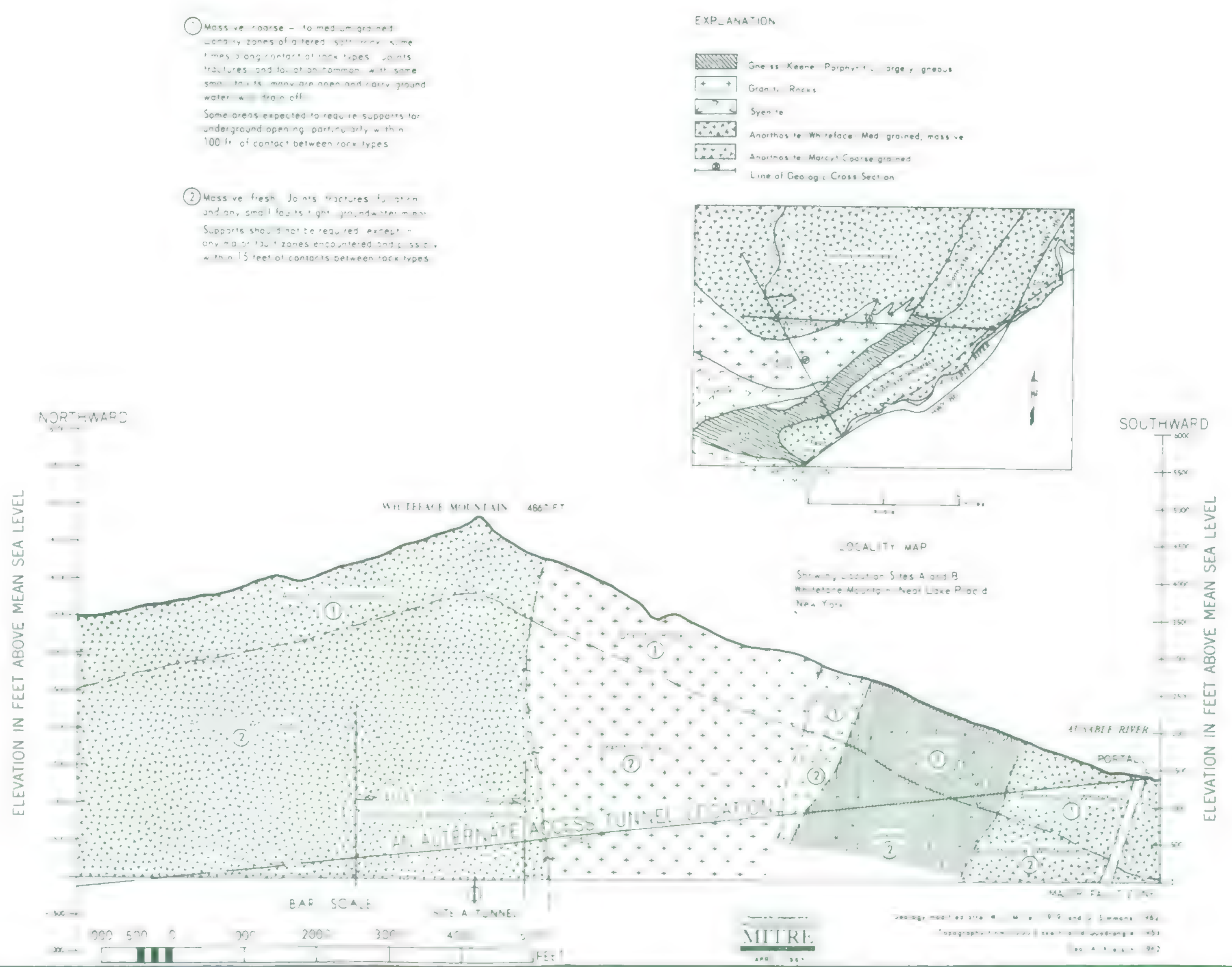
Syenite. A small wedge of syenite less than 700 feet wide occurs on the eastern margin of the granitic rocks, as shown in Fig. 5, and apparently pinches out at a depth of some 2200 feet. This syenite body is similar to the wedge-shaped body of syenite encountered along the alignment of Site A, Whiteface Mountain,

Fig. 5

WHITEFACE MOUNTAIN, NEAR LAKE PLACID, NEW YORK Site B

Looking Eastward along Geologic Cross-Section

South 29°00′ East in Lat. 44°22′, Long. 73°47′



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although the two are separate in outcrop and do not appear to be connected at depth. The physical properties of this rock are described under Site A.

Gneiss. A wedge-shaped mass of gneiss about 2200 feet wide occurs on the eastern margin of the syenite and on the western margin of a second anorthosite outcrop. This gneiss is part of the mass described under Site A. The physical properties and conditions of this occurrence are described as well.

Structural Features of Site

The structural setting of Site B is the same as that described under Site A. Areally, Site B is located within a large regional block bounded by faults on three sides, as described under Site A. The rock units are somewhat deformed due to igneous intrusion, and they possess lineation patterns typical of metamorphics (gneiss) and ancient rocks such as the anorthosite and granitics. This lineation is partly shown on the Locality Map in Fig. 5 by the outcrop trends of the granitic rocks, gneiss, syenite, and anorthosite that occur on the southern and eastern margins of Whiteface Mountain.

Although none of the structural conditions at this site appears to be of major importance in selecting the location of an access tunnel and area for a deep-underground cavity, the portal for the tunnel should be located west of the fault zone.

While the contact zone between each rock traversed by the alignment may be fractured and may constitute a structural feature which requires support in a tunnel, available evidence indicates that the contacts are tight and are not structural features of broken rock.

The body of gneiss crosscut by the access tunnel may be crushed and broken and may require special attention and supports in the tunnel. If present, the crushing and weaknesses would be due to schistosity and banding of this rock; possible conditions are described under Site A.

The area is considered to be seismically inactive.

Advantages of Proposed Tunnel Alignment

The alignment for Site B offers the general advantages described under Site A. Site A requires a longer tunnel than Site B (12,000 feet compared to 9000 feet), but it offers a deeper cover, by some 500 feet (see Figs. 4 and 5).

The Site B alignment does not pass beneath any perennial streams flowing off the slopes of Whiteface Mountain. Although this is not of importance in areas where cover rock is over 1000 feet thick, the location of perennial streams may prove important where cover is less than 1000 feet, due to the increased number of fractures which would allow ground water circulation. By comparison, the alignment for Site A traverses beneath two tributaries of the West Branch, Ausable River; both, however, are in areas where cover rock is greater than 1000 feet.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general condition of all rock types within the near-surface zone of 500 to 1000 feet is given in Fig. 5. A further description of the conditions to be expected is given under Site A.

The possible access tunnel location shown in Fig. 3 requires some 9000 feet of inclined (5° 40') tunneling to attain a cover rock of 4100 feet. Support and reinforcement will be required in the vicinity of the portal and perhaps to depths of 500 feet or more of cover for conditions as described under Site A. The portal should be located west of the fault zone to avoid the crushed rock therein.

The anorthosite-gneiss contact will be encountered at a point where the cover is some 800 feet thick. Under these conditions, this contact may create problems due to possible strong fracturing and excessive inflow of ground water, and, in general, may require special attention and support.

The contact between the gneiss and syenite units and the syenite and granitic rocks occurs at a point where the cover is some 2000 feet. Under these conditions, it is anticipated that these contacts will be tight and will offer no particular difficulties. Similarly, the contact between the granitic rocks and the main anorthesite mass will be encountered at a point where the cover is some 3700 feet. The conditions anticipated at this contact and tunneling are described under Site A.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

The rock within the vicinity of the proposed deep-underground cavity, Site B (4000 to 4400 feet of cover) is a massive, coarse-grained anorthosite. This rock is of similar properties to "granite" as described under Site A.

As shown in Fig. 3, the contact between the anorthosite and granitic rocks may occur near or within the area for a potential deep-underground cavity. Due to the strong, tight, and gradational conditions anticipated for this contact, no particular difficulties are foreseen; the granitic rock is of equally good quality for a potential deep-underground cavity.

Dominant Favorable Features of Deep-Underground Site

Although Site B offers the same general advantages described for Site A, the proposed access tunnel location does not provide as thick a rock cover; but, on the other hand, the access tunnel for Site B is some 3000 feet shorter than for Site A.

Only static stresses should be active at depths of the proposed cavity, Site B, due to conditions as described under Site A.

Adverse Features of Deep-Underground Site.

A large subsurface area with at least 5000 feet of cover rock is difficult to attain at this site. The reasons for this situation and possible ways to improve the site to attain a greater subsurface area are described under Site A.

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SOUTHEASTERN UNITED STATES

Mt. Mitchell, North Carolina - Site A
(Latitude 35° 46', Longitude 82° 16')

Geographic Location and Accessibility

A deep-underground site is proposed beneath Mt. Mitchell, North Carolina. Site A is located on the eastern slope of Mt. Mitchell at a point some 14 airline miles northwest of Marion, North Carolina, (see the Locality Map in Fig. 6).

The portal of the proposed site is easily accessible from Marion via Highway 80 to Buck Creek Gap, and thence westward via secondary road for some three miles to the portal along the South Toe River. Railroad facilities are available at Marion, and the Knoxville and Salisbury Line of Southern Railroad is within four airlines miles of the site,due south at Round Knob.

The site alignment is along an east-west trend from a point just west of the South Toe River due west through Mt. Mitchell. This site is well-removed from populated areas, yet within reasonable distance of rail and highway facilities.

Site Topography

Mr. Mitchell is an area of moderate to steep slopes; the topography is shown in Figure 6. From the proposed portal at an elevation of approximately 3100 feet, the topography rises gently within a distance of some three miles to an elevation of 6711 feet at Mt. Mitchell. Topographic maps indicate the area is not very rugged, and the surface of the site is readily accessible. The gentle canyon of the South Toe River borders the site on the east. Secondary roads are located along the river. The topography and features of the area surrounding Mt. Mitchell are given on U.S. Geological Survey Quadrangle map, Mount Mitchell, edition 1902, at a scale of 1:125,000 and a contour interval of 100 feet. A U.S. Geological Survey folio, No. 124 (1905),[12] and the Geologic Map of New York (1962)[13] describe the geologic features, rock conditions, and general geology of this region in detail.

Geologic Setting

This site is located on the eastern flank of Mt. Mitchell in an area of several metamorphic rocks which grade into one another. Grossly, these metamorphics are similar in composition and physical properties, and they represent very ancient sediments

that were folded, faulted, and changed back in pre-Cambrian time. Since the pre-Cambrian, they have been further deformed and metamorphosed both during the Appalachian Mountain-building at the end of the Paleozoic, and also to a small degree during the uplift of the Appalachians to their present height. Regionally, Mt. Mitchell is within the center of a northeastward-trending belt of folded metamorphic rocks and is the highest topographic feature east of the Rocky Mountains. This northeast-trending belt of folded and faulted metamorphics has been intruded by igneous rocks at numerous localities. Due to the folded and arched configuration of Mt. Mitchell, it is possible that igneous rock occurs in the core of this mountain within depths of 5000 feet. No drill holes or subsurface data are available concerning the rock of the central core of Mt. Mitchell.

Rock Units of Site

The Mt. Mitchell area consists largely of various metamorphic rocks which are grouped together as the Carolina gneiss. This very ancient rock (pre-Cambrian) consists of alternating bands and bodies of mica-gneiss and mica-schist, with some granite-gneiss, schist, granite, and diorite. Locally, within the gneiss and schist rocks are small lenses of marble and other ancient sedimentary rocks.

The individual bodies of gneiss, schist, and granitic rocks
have not been separated out as distinct map units by investigators 12
and, therefore, areas of each rock are not shown on the Locality Map or the cross-section in Fig. 6. The bands, lenses, and tabular masses of each rock type occur mainly parallel to each other and trending northeastward.

Structural Features of Site

The principal structural feature of Site A is the broad, northeastward-trending uplift that deforms the Carolina gneiss. This broad fold is plotted in Fig. 6; the various metamorphic rocks comprising the Carolina gneiss occur as steeply-dipping, overturned units throughout the eastern half of the site. Near the center of the site the ancient rocks are overturned, occurring throughout the main Mt. Mitchell area as a broad, arch-like series that dips roughly parallel to the surface topography. This arched structure is a common relationship for ridges that are underlain by an igneous intrusive.

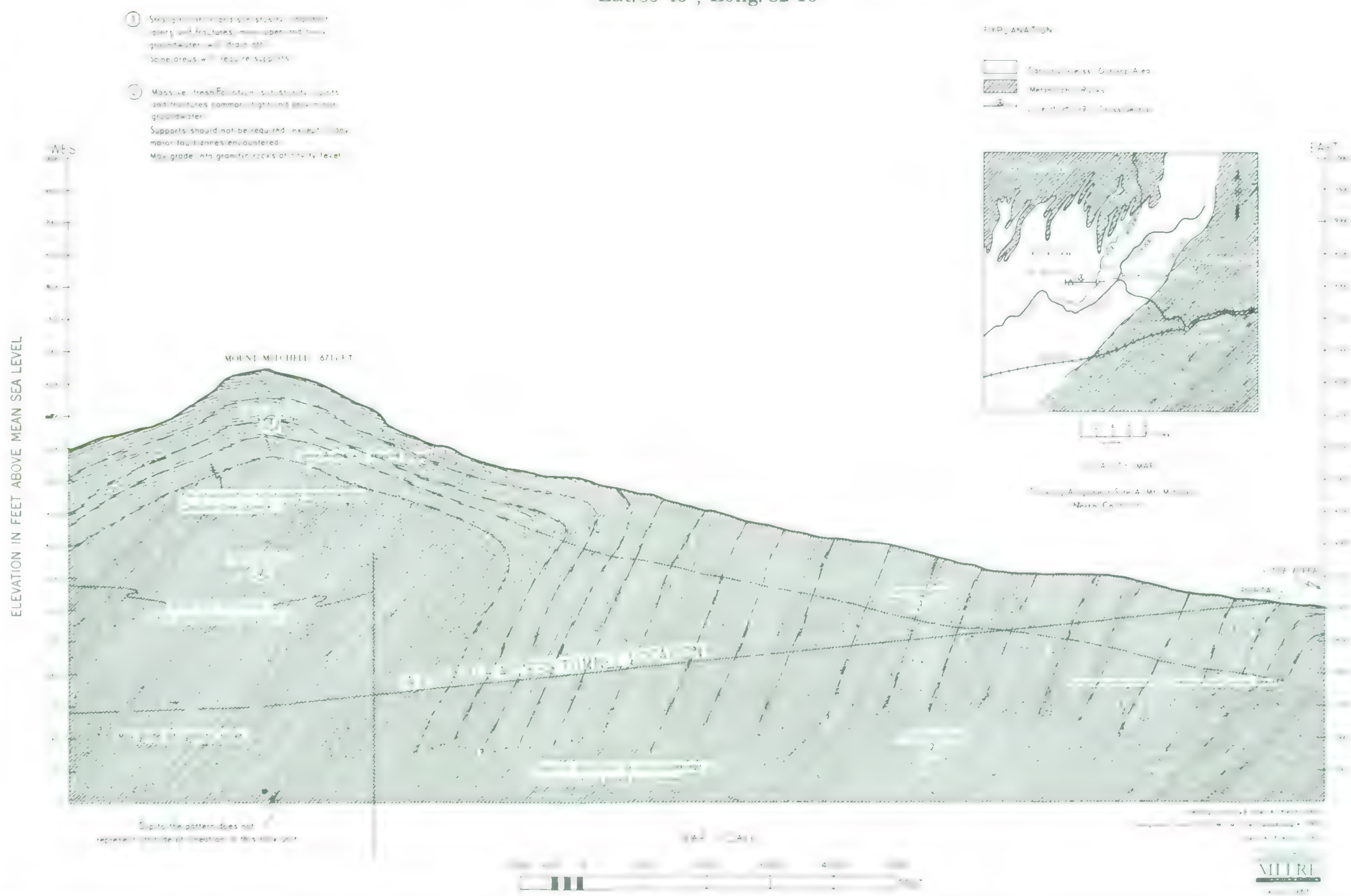
The structural trends of Mt. Mitchell represent bands, lenses, and irregular granitic rock bodies in contact with one another; the total group comprises the Carolina gneiss.

Fig. 6

MOUNT MITCHELL, NORTH CAROLINA Site A

Looking North along Geologic Cross-Section from South Toe River East Through Mt. Mitchell

Lat. 35°46', Long. 82°16'



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Individual contacts between the respective rock types may be represented by small-scale fault planes, by foliation or schistosity planes, or by solid, welded contacts between two gradational rocks. In the case of faults, foliation, or schistosity, the contact zone may be broken, constituting a structural feature which requires support in a tunnel. This is particularly true for contacts encountered along the tunnel where cover is less than 1000 feet; below depths of 1000 to 2000 feet, however, structural features along the contacts should be tight and similar in properties to the gradational or welded contacts.

None of the major structural conditions at this site appears to be of major importance in selecting the location of an access tunnel and area for a deep-underground cavity. The east-west alignment for Site A does not intersect at right angles the northeastward-trending folds and structures of Mt. Mitchell. While the ideal alignment for tunneling conditions would be to intersect the northeastward-trending bands of rock at right angles with a tunnel alignment trending northwest, no portal locations are available on the southeast flank of Mt. Mitchell that offer as good conditions as Site A on the east flank.

The area is considered to be seismically inactive.

Advantages of Proposed Tunnel Alignment

Sites of steep topography are scarce in the southeastern part of the United States, particularly sites with fair-to-good subsurface rock conditions. Site A is a deep-underground site accessible by a tunnel approximately 14,000 feet in length. The access tunnel of Site A traverses beneath a prominent ridge and thereby gains the maximum thickness of cover along the access tunnel.

The Site A alignment does not pass beneath any perennial streams flowing off the slopes of Mt. Mitchell. The alignment traverses beneath the ridge mentioned earlier, thereby reducing the near-surface infiltration of ground water along the joints and fracture system of the metamorphics. No appreciable ground water is expected at the depth of the potential underground cavity in the Carolina gneiss.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general rock conditions anticipated along the proposed alignment of Site A are shown in Fig. 6. Within the first 4000 feet of tunnel, the Carolina gneiss is expected to possess an

abundance of weathered zones, joints and fractures, and a strong schistosity. The fractures and schistosity planes are expected to carry ground water of varying quantities.

From a point about 4000 feet along the tunnel to the area of the potential deep-underground cavity, the access tunnel will be driven in the steeply-dipping (overturned) Carolina gneiss units, as shown in Fig. 6. Many individual boundaries will be crossed between lenses and irregular-sized masses of gneiss and schist, and schist and granite, and in some cases, between these rocks and marble and ancient sediments. Since some of these contacts are expected to be highly fractured and to carry ground water in limited amounts, supports may be required.

The true attitude of the Carolina gneiss bands and folded structure is unknown at depths of 5000 feet below Mt. Mitchell, but their attitude is expected to dip steeply toward the west in a continuous pattern as shown in Fig. 6 (east side)

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

The rock within the vicinity of the proposed underground cavity at Site A, at a distance of 12,000 to 14,000 feet from the portal, is expected to be hard, durable Carolina gneiss that consists of gneisses, schists, granitic rocks, and some blocks of ancient sediments. The strength and physical properties of this group of variable rocks is expected to be average. If detailed studies determine that the proportion of actual gneiss is high, or if, even better, granite and gneiss are the main rocks within the cavity area, rock conditions would be of high strength and good physical properties, similar to sites described in Figs. 3, 7, and 8.

If the core of Mt. Mitchell is an igneous intrusive at a depth of 5000 feet, the general conditions of Site A would be somewhat improved. This would afford a more uniform rock of high quality for the cavity construction, and furthermore, would provide the additional advantages of a "layered" cover rock as described in the discussion on Mt. Washington.

Except as noted, supports should not be required along an average-sized tunnel. Requirements for supports and reinforcement within the cavity will be directly related to the size of the underground openings constructed.

Dominant Favorable Features of Deep-Underground Site

Three features of Site A are worthy of special mention:

a. The inherent structural features of the Carolina gneiss throughout the Mt. Mitchell area and directly above the proposed underground cavity are in a domal or umbrella-like pattern. This pattern of foliation, schistosity, and fractures has the ability to function in part like alternating competent and incompetent beds in the dampening or dissipation of the dynamic stresses mentioned above.

b. The Appalachian Mountains and the Mt. Mitchell area were formed in ancient geologic time, over 185 million years ago. Consequently, the tectonic stresses associated with the uplift and deformation of these rocks have largely or fully decayed. Only static stresses should be active at the proposed cavity depth.

c. The pre-Cambrian Carolina gneiss consists of an ancient series of rocks that have been exposed to surface erosion and deterioration for a long time. Consequently, the rocks now occurring at a depth of some 5000 feet below Mt. Mitchell are expected to be relatively fresh, hard, and durable (weathered, upper portions removed). Structural features present should be tight. No large zones of breccia or open fractures are expected, as these rocks were formerly buried at much greater depths and only recently (Miocene-Pliocene time) re-elevated, erosion having exhumed them at their present topographic position.

If igneous rock occurs as a deep core of Mt. Mitchell, as mentioned above under Rock Conditions Anticipated in Vicinity of Deep-Underground Site, the subsurface features for underground construction at this site will be substantially improved. Large masses of granite crop out east of the site, and this rock (Henderson granite) may occur beneath the site as the deep core under the Carolina gneiss.

Adverse Features of Deep-Underground Site

The principal adverse condition at Site A is the possibility of encountering a thick section of soft schist within the first 4000 feet of the access tunnel. This condition can be determined

in advance by normal exploration techniques, and any serious plans for construction at this site should include subsurface drilling to depths lower than the proposed tunnel and cavity. Although the steeply-dipping foliation, schistosity, and fracture system shown in Fig. 6 may appear adverse at first, this is not as serious a situation as one might at first conclude.

The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

SOUTHWESTERN UNITED STATES

Santa Catalina Mountains, Tucson, Arizona - Site A
(Township 11 South, Range 15 East)

Geographic Location and Accessibility

A deep-underground site is proposed beneath the Santa Catalina Mountains, near Tucson, Arizona. Two access tunnel alignments, with portals nearly four miles apart, are suggested, Sites A and B. Site A is located on the western flank of the Santa Catalina Mountains and is accessible by traveling some 13 miles north of Tucson, Arizona, on Highways 80 and 89, and thence 3 1/2 miles due east across desert terrain via a secondary road. The proposed portal site is easily accessible at a point adjacent to Cargodera Canyon. The location of this site is outside any populated areas, yet is within a very short distance of railway, highway, and air facilities.

The areal setting of Site A is shown on the Locality Map in Fig. 7. The access tunnel trends due east to beneath Mt. Lemmon, the highest peak in the mountains.

Site Topography

This site is located in an area of steep slopes and very rugged surface topography. From the proposed portal at an elevation of about 5000 feet the surface rises rapidly within less than a mile to an elevation of 7785 feet; eastward the surface is cut by local canyons for a distance of 4000 feet and then rises rapidly within one mile to elevations of approximately 9000 feet around Mt. Lemmon. Many of the small valleys that traverse this site are steep-walled, making foot travel extremely difficult. Streams are intermittent, and surface runoff is moderate; recharge to the ground water is low.

The topography and features of the area surrounding Mr. Lemmon and the western part of the Santa Catalina Mountains are given on U.S. Geological Survey Quadrangle map, Mount Lemmon, 1957 edition at a scale of 1:62,500, with a contour interval of 80 feet.

The two alternate access tunnels shown on the same alignment (Site A) provide a cover of 5000 feet within a length of some 11,000 feet of tunnel. The access tunnel at Site A is shorter than the alignment for Site B (see Fig. 8). Both sites in this area offer a very large subsurface area with a cover of 5000 feet or more for the deep-underground cavity.

Geologic Setting

The Santa Catalina Mountain area consists largely of two major rock types: granite, and granite-gneiss, as shown on the Locality Map in Fig. 7; these two rocks crop out over the major portion of the mountain range. The boundary between the granite-gneiss and granite, which occurs between Sites A and B, constitutes a major fault zone over one mile in width, extending across the complete range. Although drill-hole information on its attitude with depth is not available, surface evidence indicates that the zone dips very steeply to the southward. Sites A and B have been located at some distance from the zone to avoid encountering it or any subsidiary geologic structures close by that formed this major feature.

Rock Units of Site

Granite. The Catalina granite crops out over the entire area of Site A. In the vicinity of Mt. Lemmon, a thin cover of sedimentary rocks, mostly quartzite, overlies the intrusive granite; the sedimentary series is up to 700 feet in thickness, as shown on the cross-section in Fig. 7. The granite extends everywhere at depth beneath this site and is anticipated to occur well below the proposed levels of a deep-underground opening.

The Catalina granite is a massive, fine-grained to coarse, crystalline rock that possesses a variation in mineral composition due to a complex origin. Within the granitic mass many variations occur, ranging from true granite to granodiorite, and in many localities a granite-gneiss occurs as the remnants of ancient sediments that were invaded and metamorphosed by the granitic intrusion. The Catalina granite is anticipated to be in a fresh, massive, and generally high-quality condition at tunnel depths.

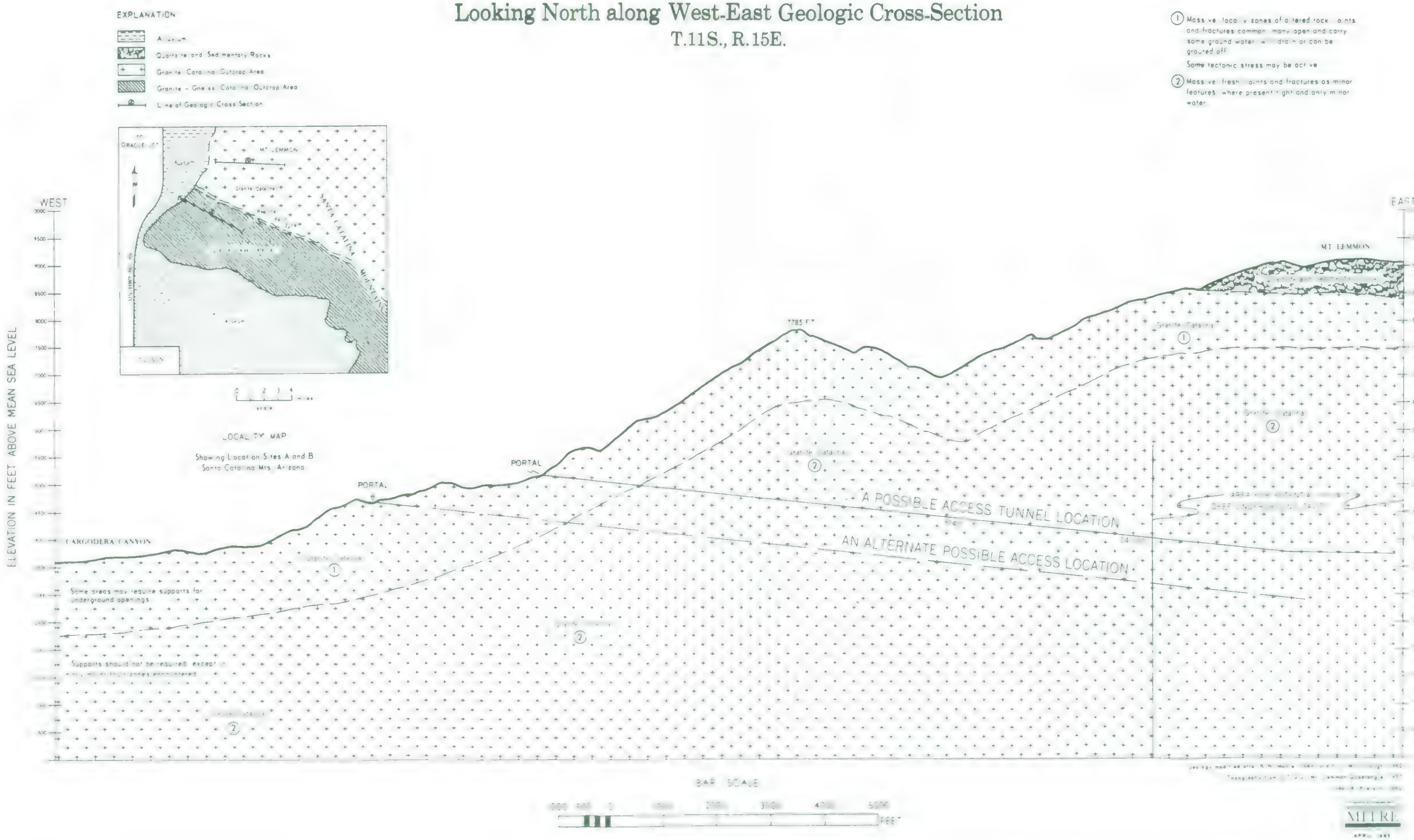
Structural Features of Site

The western Santa Catalina region is characterized by a broad "domal" uplift within this mountain belt. The Catalina granite was emplaced in Mesozoic or earlier time, although the actual date is unknown. This uplift of the mountain block occurred along major fault zones which bound the range on the west near the toe of the slope and across the southern part of the area due south of Site B (see the Locality Map in Fig. 7). Within this large block of granite, the principal structural feature is the wide fault zone located between Sites A and B. Movement along this zone and the major boundary faults has occurred since Cretaceous time, less than 70 million years ago, as younger sediments on the

Fig. 7

SANTA CATALINA MOUNTAINS, ARIZONA Site A

Looking North along West-East Geologic Cross-Section
T.11S., R.15E.



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flanks of the Santa Catalina Mountains have been faulted and folded, and this evidence suggests that the Catalina block has been uplifted at several times throughout geologic history. The most recent may have been during the Pilocene-Pleistocene time, or within the last one million years.

The Catalina granite mass possesses an abundance of joints and fractures within the near-surface zone of 1000 feet, as described in Fig. 7. Below 1000 to 2000 feet the granite is expected to be massive and fresh; any joints present are expected to be widely-spaced. Although the topographic features of the site and the history of similar intrusive rocks lead us to expect some moderate to small-scale faults throughout the granite mass, any faults encountered at depths below 1000 to 2000 feet of cover, as well as joints and small-scale fractures, are expected to be tight and to carry only limited quantities of ground water.

Due to the domal uplift and areal pattern of the Santa Catalina block, the granite possesses a definite lineation pattern and orientation of minerals throughout the mass. This orientation represents movement during the emplacement and crystallization of the rock. The lineation will have only minor effects on the tunneling and the design of any linear structures except in areas where the lineation is nearly vertical. For this reason, Site A has been located in an area where the linear structures are anticipated to be nearly horizontal and domal in their pattern; vertical or steeply-dipping lineation is more likely to occur south of Site A in the vicinity of the major fault zone (see the Locality Map in Fig. 7).

None of the structural conditions at this site is adverse in effect on the deep-underground cavity at Site A.

Although the Santa Catalina area is considered to be seismically inactive, some evidence suggests that the mountain block has been uplifted or displaced within the past one million years; thus it is possible that some further adjustment and small-scale shifting may occur in the future. This admittedly remote possibility should be considered in deciding if an installation should be made at this site.

Advantages of Proposed Tunnel Alignment

The alignment for Site A offers four major advantages:

a. The site is easily accessible from a major city via main highways and desert terrain.

b. Sufficient topographic relief is available to attain a cover thickness of 5000 feet within an access tunnel length of some 12,000 feet.

c. The deep-underground cavity is located within a massive granitic rock.

d. A large subsurface area is available with a cover of 5000 feet.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general conditions anticipated along the proposed access alignment are shown in Figure 7. Within the first 2000 feet or more of the access tunnel, the granite is expected to possess local zones of altered rock, and an abundance of joints and fractures, many of which are open and carry ground water; due, however, to the occurrence of the water and the tightening of these joints and fractures with depth, the ground water should drain off within a brief flow and create no serious problems.

Beyond the near-surface zone of 1000 to 2000 feet of cover, tunneling should encounter fresh, massive rock in which the joints and fractures are widely-spaced, tight, and carry only small amounts of ground water. Similarly, any small- to moderate-sized faults encountered at depths below 2000 feet of cover are expected to be tight and carry only small quantities of water.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

Figure 7 shows two alternate alignments for an access tunnel at Site A to extend beneath Mt. Lemmon. Both alignments are expected to encounter the Catalina granite throughout the subsurface area of the deep cavity at depths of 5000 feet or more of cover. No unusual conditions are anticipated within the area of the potential deep-underground cavity. The granite is expected to be massive and fresh, with high strength and good physical properties. Beyond the near-surface zone, supports should not be required along an average-sized tunnel, except in any fault zones or areas of high tectonic stress which may be encountered. Requirements for supports and reinforcement within the cavity will be directly related to the size of the underground openings constructed.

Dominant Favorable Features of Deep-Underground Site

Site A includes the following favorable conditions for a deep-underground site:

a. The cover rock overlying the proposed cavity in the vicinity of Mt. Lemmon consists of two distinct "layered" rock units, first the interbedded quartzite and other sediments, and second the main mass of Catalina granite. This combination of "layering" and contrasting rock types within the cover results in partial reflection of the pressure pulse due to large-scale surface or near-surface explosions. (A further explanation is given under the discussion on Mt. Washington.)

b. Several alternate depths can be chosen for driving the access tunnel at Site A. Two of these alternate alignments are shown in Fig. 7, and several others are available in the area located to the west of the lower portal at elevations between 4800 and 4000 feet along Cargodera Canyon.

c. The region of Site A was deformed in ancient geologic time (Cretaceous) and is known to have been re-elevated and deformed since then by displacement along the major fault zones. Consequently, the tectonic stresses associated with the ancient mountain-building and uplift of the Santa Catalina Mountains are expected to be largely decayed during the intervening time of some 70 million years. With readjustment and some uplift since Cretaceous times, however, some tectonic stress may be active within this range, particularly within local areas adjacent to major fault zones. This possibility should be investigated when the site is explored.

Adverse Features of Deep-Underground Site

Site A beneath the Santa Catalina Mountains possesses excellent rock characteristics and topographic features. No major adverse features are known (on the basis of existing map data) except as outlined in this report. The principal adverse feature of the region is the major fault zone located between Sites A and B, and this area was deliberately avoided in choosing the two site alignments.

The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

Santa Catalina Mountains, Tucson, Arizona - Site B
(Township 12 South, Range 14 to 15 East)

Geographic Location and Accessibility

A second deep-underground site is proposed beneath the Santa Catalina Mountains, near Tucson, Arizona. Site B is located on the southwestern flank of the mountains at a point some 11 miles north of Tucson, Arizona, and within a short distance of Highway 80 and 89. The proposed portal site is easily accessible via dirt road and desert terrain at a point adjacent to Alamo Canyon located in Sec. 4, Township 12 South, Range 14 East. The location of this site is outside the populated area but very close to housing areas under construction within two miles along Highway 80 and 89. Railroad, highway and air facilities are easily accessible at Tucson.

The areal setting of Site B is shown on the Locality Map in Fig. 8. The access tunnel trends S 59° E to beneath Window Rock.

Site Topography

This site is located in an area of steep slopes and rugged surface topography. From the proposed portal elevation of some 3600 feet, the surface rises rapidly within a mile to an elevation of 5700 feet. From this point, the topography becomes extremely rugges, with steep-walled canyons and sharp peaks, while the general surface rises gradually over a distance of nearly two miles to an elevation of 7397 feet at Window Rock.

Streams are intermittent and surface runoff is moderate; recharge to the ground water is low.

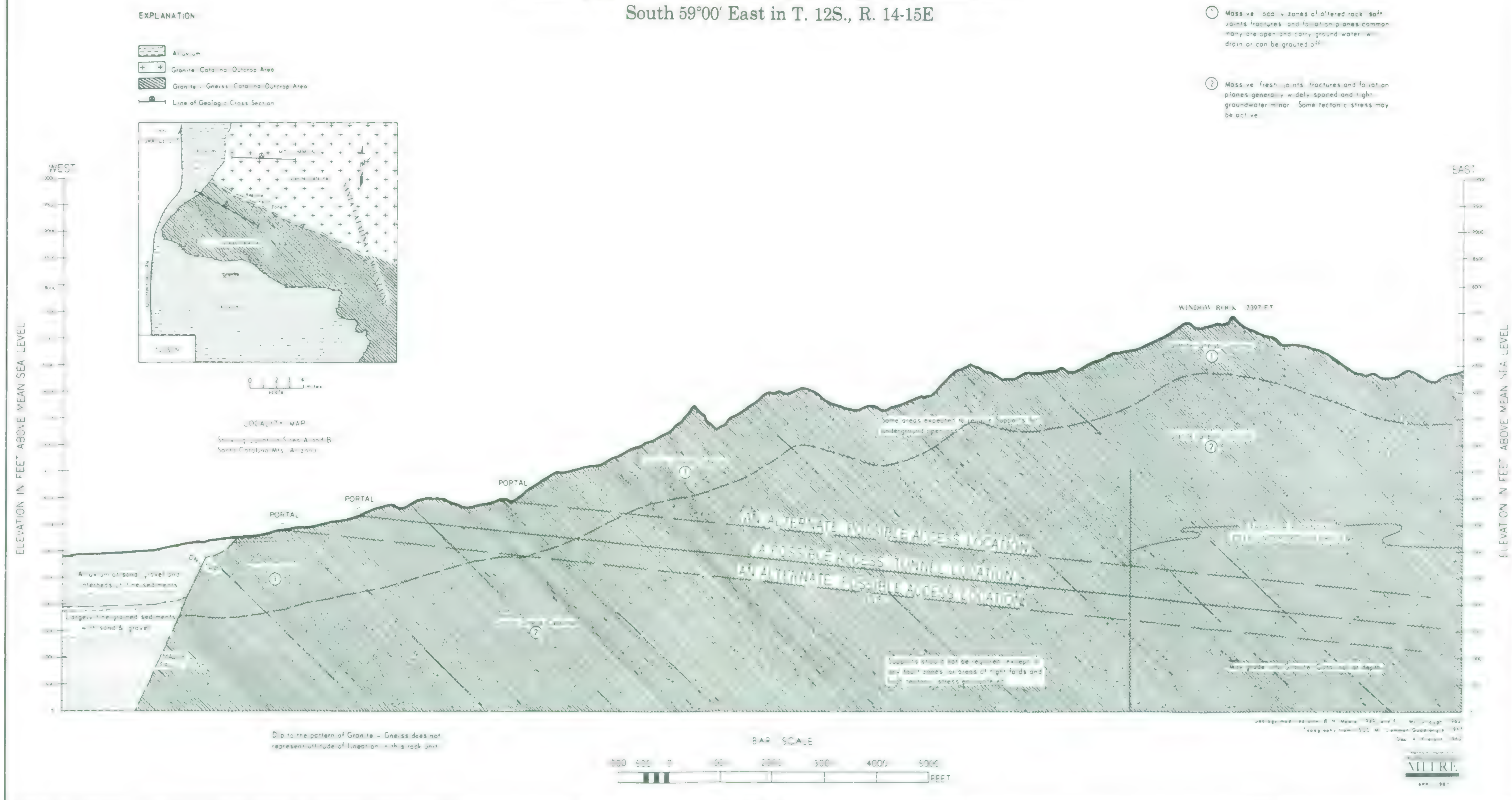
The topography and features of the area surrounding Window Rock and the western part of the Santa Catalina Mountains are given on U.S. Geological Survey Quadrangle map, Mount Lemmon, 1957 edition, at a scale of 1:62,500 and a contour interval of 80 feet.

The two alternate access tunnels shown on this same alignment, Site B, provide a cover of 5000 feet within an access of some 12,000 feet of tunnel. The length of access tunnel required at Site B is at least 1000 feet longer than that required for Site A (see Fig. 7). Both sites in this area offer a very large subsurface area with a cover of 5000 feet or more for the deep-underground cavity.

Fig. 8

SANTA CATALINA MOUNTAINS, ARIZONA Site B

Looking Northeastward along Geologic Cross-Section
South 59°00' East in T. 12S., R. 14-15E



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Geologic Setting

The Santa Catalina Mountain area consists largely of two major rock types: granite, and granite-gneiss, as shown on the Locality Map in Fig. 8. The boundary between the granite-gneiss of Site B on the south and the granite of Site A on the north occurs some two miles north of Site B. This boundary is a major fault zone over one mile in width, which traverses the complete mountain range. A further description of this fault is given under Site A.

Rock Units of Site

Granite-Gneiss. The Catalina granite-gneiss crops out over the entire area of Site B. No sedimentary rocks occur within the area as a thin cover as they do at Site A. The granite-gneiss extends everywhere at depth beneath this site. It is reasonable to expect that the granite-gneiss grades into granite at depth, which could be above 5000 feet.

The Catalina granite-gneiss is a massive medium-grained rock that possesses a marked lineation due to its metamorphic origin. Within the mass, many variations occur, ranging from true granitic rock to gneiss. In some localities the rock is a mixture of the granitic intrusive and the remnants of the ancient sediments that occur as gneiss. The Catalina granite-gneiss is expected to be in a fresh, massive, and generally high-quality condition at tunnel depths. It is possible that above the proposed depths of the tunnel or the deep-underground cavity, the gneiss may grade into the Catalina granite; this rock would have the properties described in the previous section on Site A.

Structural Features of Site

The western Catalina region is characterized by a broad "domal" uplift within this mountain belt. The principal features and geologic history of this uplift, which involve both the Catalina granite and Catalina granite-gneiss, are discussed in the previous section on Site A.

The area of Site B is influenced by a broad anticlinal fold which deforms the major part of the granite-gneiss mass. The axis of the fold trends through the central part of the mass from a point on the west at the topographic "bulge" near Highway 80-89, southeastward on an alignment that roughly parallels the regional fault zone (see the Locality Map in Fig. 8). This folding has resulted in an accentuation of the foliation structures so common

to granite-gneiss. Furthermore, near the crest and troughs of the main fold and subsidiary structures, a more extensive fracture pattern occurs that breaks the rock into a series of joint blocks. This fracturing decreases with depth.

None of the structural conditions at this site is of adverse effect to the deep-underground cavity at Site B. The strong linear structures within the granite-gneiss are not expected to be a major controlling factor in selecting the tunnel alignment.

The Santa Catalina area is considered to be seismically inactive. Further consideration of the possible effects of uplift and structural adjustment of the mountain block has been discussed under Site A.

Advantages of Proposed Tunnel Alignment

The alignment of Site B offers the following advantages:

a. It is easily accessible from a major city via highways and desert terrain.

b. It will provide some 5000 feet of rock cover using an access tunnel of approximately 14,000 feet.

c. The proposed tunnel alignment can be driven wholly within a massive granite-gneiss rock from portal to underground cavity.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general rock conditions anticipated along the alternate access tunnels are shown in Fig. 8. Within the first 4000 feet or more of the tunnel, the granite-gneiss may possess local zones of altered soft rock. Within this zone, the joints, fractures, and foliation structures are common; many are open and carry ground water, particularly within 1000 feet of surface. Since this ground water is confined to the structural breaks, it should drain off within a brief period without creating serious problems, provided the breaks are not located in a major fault zone and are not fed by surface streams or a large run-off area. The joints, fractures, and foliation planes will tighten with depth and will be more widely spaced at depths below 1000 to 2000 feet, as shown in Fig. 8.

Beyond the near-surface zone of highly fractured rock the access tunnel should encounter fresh, massive rock in which the

joints and fractures are widely spaced. Where present, these structures should be tight and should possess only minor amounts of ground water.

In some areas, the granite-gneiss mass has been tightly folded, and intricate folds and a strong lineation have developed. These structures may offer some difficulties for tunneling operations; the highly-fractured rock may carry appreciable quantities of ground water, and some alteration and softening of the rock mass may occur. Also, these folded areas may possess some active tectonic stress that has not fully decayed since the rather recent adjustment of the mountain block.

Beyond the near-surface zone, supports should not be required along an average-sized tunnel except in any fault zones or areas of high tectonic stress encountered. Requirements for supports and reinforcement within the cavity will be directly related to the size of the underground openings constructed.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

Figure 8 shows two alternate alignments at Site B for an access tunnel extending beneath Window Rock. Both alignments are expected to encounter the Catalina granite-gneiss throughout the subsurface area of the deep cavity and at depths of some 5000 feet. As described earlier, the Catalina granite-gneiss may grade into the Catalina granite at depths encountered near the deep underground site. No unusual conditions are anticipated within the area of the potential deep-underground cavity. The granite-gneiss at depths of some 5000 feet is expected to be massive and fresh, with high strength and good physical properties. If the Catalina granite occurs at these depths, the conditions described under Site A would occur.

Dominant Favorable Features of Deep-Underground Site

Site B includes the following desirable conditions for a deep-underground site:

a. The access tunnel and cavity are driven wholly within the same rock type, which possesses the characteristics of a granitic rock.

b. Several alternate depths can be chosen for driving the access tunnel at Site B. Two of these alternate alignments are shown in Fig. 8 and others are available in the immediate area.

recurring movement has taken place along the boundary faults, and that the block has been adjusted several times.

On the western flank of the range, typical desert alluvium, consisting of sand and gravel with interbedded claystone and other sediments, overlies the basement of gneiss-granite in the vicinity of the alternate portal.

Rock Units of Site

Gneiss-Granite. The ancient pre-Cambrian gneiss-granite is the principal rock of Site A occurring as the main core of the Virgin Mountains. Throughout the site, a sequence of sedimentary rocks overlies the gneiss-granite, as described under the heading Geologic Setting. The gneiss-granite extends everywhere at depth beneath the site, with the exception of an area of some 700 to 1200 feet along the access tunnel alignments. This rock may grade into granite at depth.

The gneiss-granite is a strongly foliated and banded rock that is a combination of ancient metamorphic rocks intruded by granite masses. The strongly banded gneiss is a medium-grained rock, while the granite is medium-to coarse-grained. The physical properties of the gneiss-granite are similar to those of a massive granitic rock. The rock is expected to be in a fresh, massive, and generally high-quality condition at depths below 2000 feet. It is possible that within the proposed depths of the access tunnel or the deep-underground cavity, the gneiss may grade into granite, which is intruded throughout the gneiss as dikes and irregular-shaped masses. (A similar situation is described under Site B, Santa Catalina Mountains.)

Sedimentary Rocks. The sequence of sedimentary rocks that overlie the gneiss-granite is described briefly under the heading Geologic Setting, and is shown in Fig. 9. These rocks provide advantageous cover for underground construction, as described under the heading Dominant Favorable Features of Deep-Underground Site. Three of the rock units (limestone, shale, and sandstone) are expected to be encountered along the access tunnel alignments shown in Fig. 9. The conditions anticipated within these rocks along the tunnels (principally large quantities of ground water flow, and weak or broken rock) are described below.

Structural Features of Site

The Virgin Mountain block is characterized by a broad arch or anticlinal structure. The core of the range, gneiss-granite, is an ancient pre-Cambrian rock mass that was uplifted in the Cretaceous

c. The region of Site B was deformed in ancient geologic time, as described under Site A. The possibility of latent tectonic stress within parts of this site has been described for Site A.

Adverse Features of Deep-Underground Site

Site B beneath Window Rock of the Santa Catalina Mountains possesses good quality rock characteristics and topographic features. The location of Site B, within the granite-gneiss mass with its folded structures, is not as favorable a location as Site A, Santa Catalina Mountains. Although the proposed tunnel access is located parallel to the folded structures in order to realize the maximum advantages for tunneling operations, the folds are known to have developed excessive fracturing along their alignment, and this feature may be encountered by the access tunnels. Site B as located is parallel to the main anticlinal fold and is located on the northeast flank in rocks that have been less deformed and fractured than those occurring directly north of the site.

The tectonic deformation accompanying the fold undoubtedly developed some tectonic stresses in the granite-gneiss mass. As the Catalina Mountains are relatively young, having been uplifted as recently as Pliocene time, it is possible that some of the induced tectonic stress remains active (unreleased). The design of a deep cavity at Site B should include a consideration of the possibility of additional stresses of a tectonic origin.

The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

Virgin Mountains, Arizona (NW Corner) - Site A
(Latitude 36° 52', Longitude 113° 48')

Geographic Location and Accessibility

A deep-underground site is proposed beneath the Virgin Mountains of northwestern Arizona, located some two miles due east of Littlefield. The site is easily accessible via dirt road over flat desert terrain from Littlefield, which is on U.S. Highway 91. St. George, Utah, is 17 miles northeast, and Las Vegas, Nevada, is 90 miles southwest via Highway 91.

The alternate portals of Site A are at the western toe of the main Virgin Mountain range, located at elevations of 2200 to 2400 feet. This site is removed from any populated areas, yet is within a short distance of a U.S. Highway and the main line of Union Pacific

Railroad at Glendale, Nevada, some 41 miles south via Highway 91, or 36 miles airline to the west.

The areal setting of Site A is shown on the Locality Map in Fig. 9. The access tunnel trends due east beneath the main range of the Virgin Mountains.

Site Topography

This site is located in an area of steep slopes and moderately rugged surface topography. From a proposed portal at an elevation of some 2400 feet, the surface rises rapidly in a little more than a mile to an elevation of nearly 6000 feet (see Fig. 9). The Virgin Mountains at this site are a symmetrically-arched range which has been moderately eroded with broad canyons and gentle surface features. Streams are intermittent, and surface runoff is moderate; recharge to the ground water is low.

The topography and features of the area surrounding the Virgin Mountains are given on U.S. Army Map Service Quadrangle sheet, Las Vegas.

The two alternate access tunnels shown on the Site A provide a cover of 5000 feet within a tunnel length of some 13,000 and 15,000 feet respectively. The minimum access tunnel at Site A is some 4000 feet longer than the access for Site B (see Fig. 10). Site A offers a large subsurface area with a cover of 5000 or more feet for the deep-underground cavity.

Geologic Setting

The Virgin Mountains area consists of a major fault block of gneiss-granite, which has been uplifted along boundary faults, as shown in Fig. 9. The broadly folded or arched range consists of a gneiss-granite core that is overlain by a sequence of younger sedimentary rocks varying from 700 to 2300 feet in thickness according to the topography. At the base of the sequence is a relatively uniform thickness (200 feet) of Tapeats sandstone, followed by some 300 feet of Bright Angel shale, than 800 feet of undifferentiated limestone which is overlain by the massive Redwall limestone up to 900 feet thick. A cover of the thin-bedded Callville limestone occurs as a cap in the eastern section of the site, ranging from 100 to 200 feet in thickness.

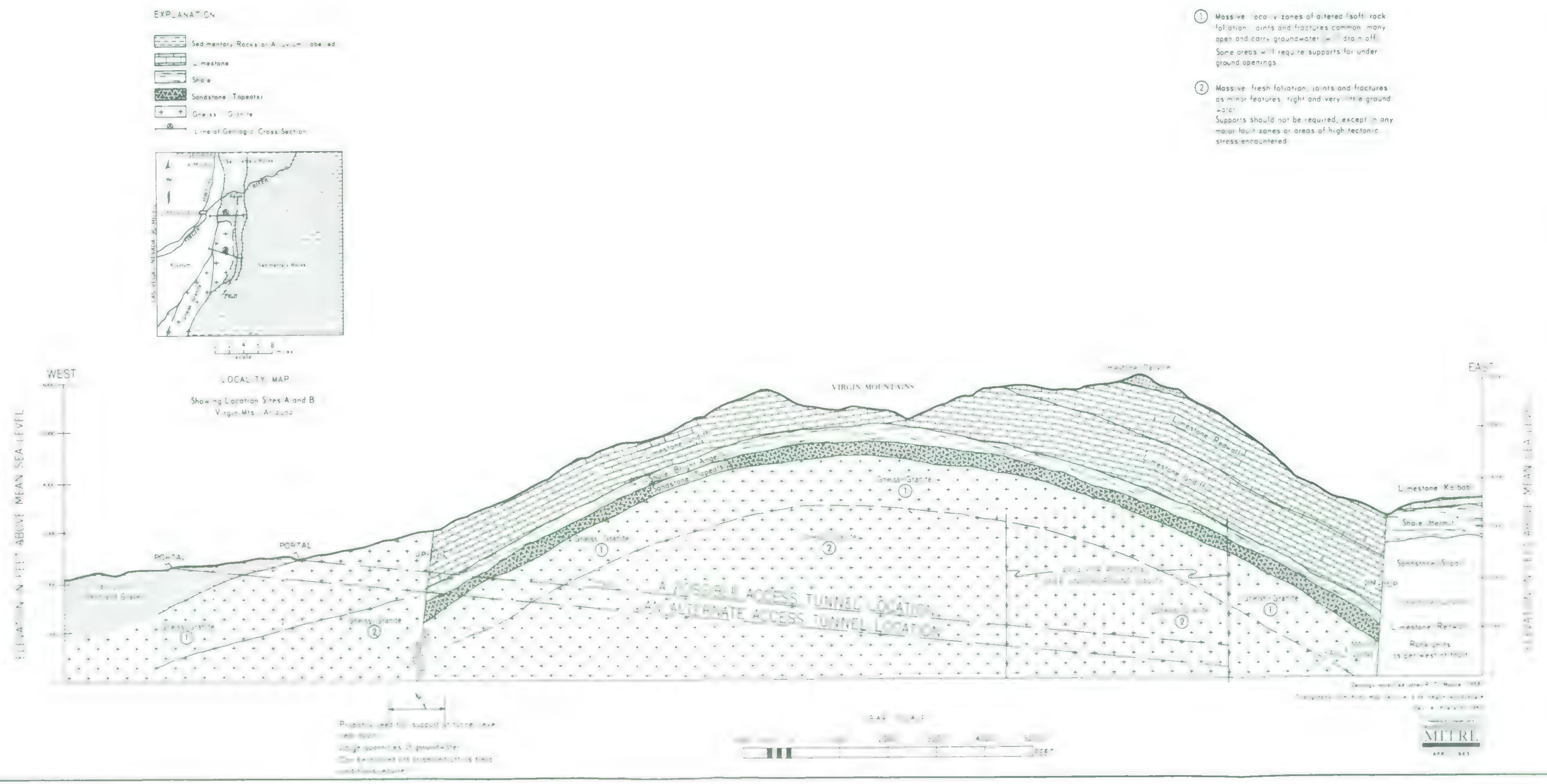
The Virgin Mountain block or anticline was uplifted along pre-existing fault zones during the Cretaceous and early Tertiary time; i.e., movement was in progress less than 70 million years ago. Since this initial arching and uplift, field evidence suggests that

Fig. 9

VIRGIN MOUNTAINS,
N W ARIZONA Site A

Looking North along West-East Geologic Cross-Section

Lat. 36°52', Long. 113°48'



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and early Tertiary time along major boundary faults both on the west and east. The extent and trend of these faults are shown on the Locality Map in Fig. 9. Since this initial arching and uplift, recurring movement has taken place along the boundary faults (and along other faults within), and the mountain block has been adjusted and moved several times. The most recent movement may have been during the Pliocene-Pleistocene time, or within the last one or two million years.

The mass of gneiss-granite is strongly banded. This inherent structural feature is more or less parallel to the fault zones and the folding structures (Moore, 1958[17]). Within the block of Site A, strong banding occurs that dips from vertical near the crest, to 60° eastward on the west flank and 50° west on the east flank of the range. This rock possesses an abundance of joints, fractures, and foliation planes throughout the near-surface zone of 1000 feet, as described in Fig. 9. Below the level of 1000 to 2000 feet, the gneiss-granite is expected to be massive and fresh, with widely spaced fractures. Undoubtedly, some moderate to small-scale faults occur throughout the mass as anticipated from the topographic features of the site and the history of similarly arched blocks of ancient rocks. For example, an abundance of such fracturing is expected near the crest of the fold. As with the joints and other small-scale fractures, however, any faults encountered at depth below 1000 to 2000 feet of cover are expected to be tight and to carry only limited quantities of ground water.

The axis of the broad anticline within the Virgin Mountain block trends north-south parallel to the range, and the tunnel alignment is perpendicular to this structural feature. This folding has resulted in an accentuation of foliation and lineation structures so common to gneiss-granite rocks. The "domal" symmetry of these small-scale structures may be pronounced on the western edge of the site and within the first 1000 feet of gneiss-granite encountered along the tunnel after entering the main block. These inherent structures will decrease with depth as the central part of the block is traversed.

None of the structural conditions at this site is of serious adverse effect on the construction of a deep-underground cavity. The strong linear and foliation structures within the gneiss-granite are considered to be only a minor controlling factor in selecting the tunnel alignment.

Although the Virgin Mountain area is considered to be seismically inactive, evidence suggests that the mountain block may have experienced some readjustment and shifting within the past one or two million years; thus it is possible that some tectonic stress may be

active within this range, particularly in local areas adjacent to the major fault zones.

Advantages of Proposed Tunnel Alignment

The alignment for Site A offers four major advantages:

(a) It is easily accessible from a main highway, and there are railroad facilities nearby.

(b) The deep-underground cavity is located within a massive gneiss-granite, and most of the access tunnel is driven in this rock.

(c) A thick sedimentary cover overlies the main mass of gneiss-granite and improves the damping potential of the rock cover of the site.

(d) An extremely large subsurface area with 5000 feet of cover is available.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general conditions anticipated along the proposed access alignment are shown in Fig. 9. Within the first 2000 feet along the upper possible access alignment, the tunnel will be driven in gneiss-granite with less than 700 feet of cover rock. This section is expected to possess local zones of altered rock and an abundance of joints, fractures, and foliation planes which are open and carry ground water (which will drain off); strongly broken rock may be present in the vicinity of the major fault zone. Reinforcing supports will probably be needed throughout most if not all of this section, particularly in the vicinity of fault zones.

Beyond the major fault zone, at about 2000 feet from the portal the tunnel encounters some 1200 feet of limestone, shale and sandstone beds that overlie the main mass of gneiss-granite. Within this section, where cover rock is less than 1000 feet thick, the sedimentary rocks are expected to be fractured, faulted, and broken, providing a weak condition for tunneling. Reinforcing supports will probably be required throughout part and possibly most of this sector. A strong ground water flow is likely within the Tapeats sandstone, particularly near the base and the contact with gneiss-granite. Similarly, within the limestone beds, ground water may occur in quantity near the base and above the impervious shale (Bright Angel) unit. Because of the limited recharge area for both these potential water-bearing rocks, the ground water will drain to small quantities within a reasonable time.

Below the sedimentary cover the initial 1000 or more feet of gneiss-granite encountered along the tunnel alignment is expected to be fractured, to contain local zones of altered (soft) rock, and to carry ground water as described in Fig. 9. Supports will be required in some areas.

Beyond a point some 4500 feet from the portal, and where cover rock is in excess of 2000 feet, tunneling should encounter fresh, massive rock in which joints and fractures are widely-spaced, tight, and possess only minimal amounts of ground water. Similarly, any small to moderate-sized faults encountered at depths below 2000 feet of cover are expected to be tight and carry only minimal quantities of water.

An alternate access tunnel alignment is shown that is some 2000 feet longer than the upper tunnel. This alignment is collared in an area of alluvium and would require some 1000 feet of open cut or shallow cut-and-cover tunnel, before encountering the gneiss-granite block west of the major fault zone. This alignment traverses the area of the major fault zone at a depth 400 feet below the other access proposed, and consequently cross-cuts only 700 feet of sedimentary rocks before encountering the main mass of gneiss-granite. Tunneling conditions along this alignment are expected to be similar to those described for the upper access. Rock conditions near the main fault zone and within the shale and sandstone beds may be more broken and fractured then for the upper alignment, and the rock may carry large quantities of ground water due to the proximity of the fault zone and underlying gneiss-granite mass.

Rock Conditions Anticipated in Vicinity Deep-Underground Site

Figure 9 shows two access tunnel locations for a potential deep-underground area beneath the Virgin Mountains. Both alignments are expected to encounter the gneiss-granite throughout the subsurface area of the deep cavity at depths of 5000 feet or more of cover. No unusual conditions are anticipated within the area of the deep cavity; ground water occurrence along fractures is expected to be minimal. The rock is expected to be fresh, massive, and of high strength. The gneiss-granite may grade into a granitic rock in the vicinity of the cavity, but this change in rock would not worsen tunneling or design conditions and might even improve them.

Some areas of active tectonic stress may be encountered, but if so, this stress is expected to be of moderate to low intensity.

Supports should not be required along an average-sized tunnel except in any fault zones or areas of high tectonic stress encountered.

Requirements for supports and reinforcement within the cavity will be directly related to the size of the underground openings constructed.

Dominant Favorable Features of Deep-Underground Site

Site A includes the following desirable conditions for a deep-underground site:

(a) The cover rock overlying the proposed cavity throughout the site consists of three or more distinct "layered" rock units which are of different physical properties (limestone, shale, sandstone). This combination of "layering" and contrasting rock types within the cover results in partial reflection of the pressure pulse due to large scale surface or near-surface explosions. A further explanation appears in the discussion of Mt. Washington.

(b) The tunneling conditions for most of the access and all of the cavity area are within a massive rock with properties similar to those of a granite.

(c) A large subsurface area with 5000 feet of cover is available.

(d) The region of Site A was deformed by the uplift and broad arching of the Virgin Mountain block in Cretaceous and early Tertiary time and since then has been uplifted again by movement along the major faults bounding the range. As the last movement was a million or more years ago, any tectonic stress that remains within the range should be of very small to low intensity. The possibility of some areas possessing active tectonic stresses should be considered, as uplift in late Tertiary or Pleistocene time readjusted the mountain blocks, and this may have developed stresses that today are partially retained as local "pockets".

Adverse Features of Deep-Underground Site

On the basis of knowledge available from the geologic literature and reports on this area, this site is largely free of any adverse features. Small- to moderate-sized fault zones undoubtedly occur throughout the gneiss-granite block, but where encountered below depths of 2000 feet, these fault zones are expected to offer no particular tunneling difficulties. The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

This site requires a longer access tunnel (13,000 to 15,000 feet) to attain a cover of 5000 feet than some of the other sites described in this report.

While the major fault zone traversed near the portal of the access tunnels will require exploration and investigation before any full site study is undertaken it is expected to present no unique or extremely hazardous conditions for tunneling.

Virgin Mountains, Arizona (NW Corner) - Site B
(Latitude 36° 46', Longitude 113° 51')

Geographic Location and Accessibility

A second deep-underground site proposed beneath the Virgin Mountains of northwestern Arizona is located some six miles due south of Littlefield, Arizona. The site is easily accessible via dirt road over flat desert terrain from Littlefield, which is on U.S. Highway 91. St. George, Utah, is 17 miles northeast, and Las Vegas, Nevada, is 90 miles southwest of Littlefield via Highway 91.

The alternate portals of Site B, at the western toe of the main Virgin Mountain range, are located at elevations of 3700 and 4500 feet. This site is removed from any populated areas, yet is within a short distance of a U.S. Highway and the main line of Union Pacific Railroad at Glendale, Nevada, some 41 miles south via Highway 91, or 36 miles airline to the west.

The areal setting of Site B is shown on the Locality Map in Fig. 10. The access tunnel trends S 73° E to beneath Mt. Bangs, one of the highest peaks of the Virgin Mountains.

Site Topography

This site is located in an area of steep slopes and moderately rugged surface topography. From a proposed portal at an elevation of some 3700 feet, the surface rises rapidly in less than two miles to an elevation of 8640 feet at Mt. Bangs (see Fig. 10). Eastward from Mt. Bangs, the topography is very moderate. The Virgin Mountains at this site are a partly-arched range which has been stripped of all overlying sedimentary rocks throughout the crest and western flank of the mountains. Streams are intermittent, and surface runoff is moderate; recharge to the ground water is low.

The topography and features of the area surrounding the Virgin Mountains are given on U.S. Army Map Service Quadrangle sheet, Las Vegas.

The possible access tunnel shown on the Site B alignment provides a cover of 5000 feet within a length of some 9000 feet. The minimum access tunnel at Site A is some 4000 feet longer than this alignment (see Fig. 9). This site offers a limited subsurface area with a cover of 5000 feet or more for a deep-underground cavity.

An alternate tunnel alignment at Site B provides a cover of 4000 feet within a tunnel length of some 7000 feet, according an excellent site if less cover is allowable.

Geologic Setting

The Virgin Mountains area consists of a major fault block of gneiss-granite, which has been uplifted along boundary faults, as shown in Fig. 10. The broadly folded or arched range consists of a gneiss-granite core that is overlain on the east flank by a sequence of younger sedimentary rocks up to 2000 feet thick according to the topography. At the base of the sequence is a relatively uniform thickness (400 feet) of Tapeats sandstone, followed by some 300 feet of Bright Angel shale, and then up to 1300 feet of undifferentiated limestone. Erosion has stripped the sediments from the Mt. Bangs area and the western flank of the range.

The Virgin Mountain block was uplifted as an anticlinal structure along pre-existing fault zones during the Cretaceous and early Tertiary time; i.e., movement was in progress less than 70 million years ago. Since this initial arching and uplift, field evidence suggests that recurring movement has taken place along the boundary faults, and the block has been adjusted several times.

Rock Units of Site

Gneiss-Granite. The ancient pre-Cambrian gneiss-granite is the only rock encountered at Site B, occurring as the main core of the Virgin Mountains. Throughout the eastern flank of the site, a sequence of sedimentary rocks overlies the gneiss-granite, as described under the heading Geologic Setting. The gneiss-granite extends everywhere at depth beneath the site and may grade into granite at depth.

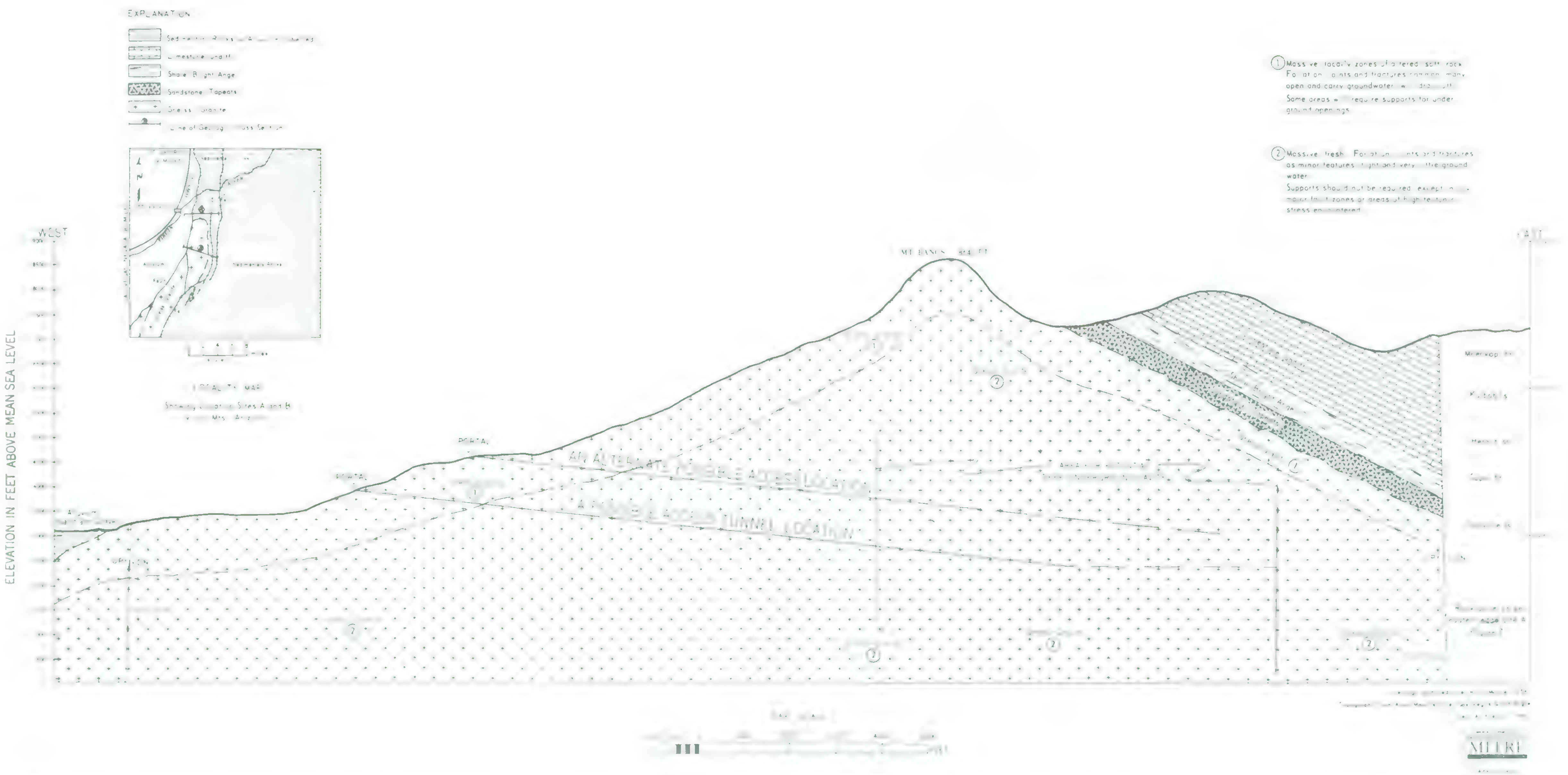
The gneiss-granite is a strongly foliated and banded rock that is a combination of ancient metamorphic rocks intruded by granitic masses. The strongly banded gneiss is a medium-grained rock, while the granite is medium- to coarse-grained. The physical properties of the gneiss-granite are similar to those of a massive granitic rock. The rock is expected to be in a fresh, massive, and generally high-quality condition at depths below 2000 feet of cover. It is

Fig. 10

VIRGIN MOUNTAINS,
N W ARIZONA MT. BANGS Site B

Looking Northward along Geologic Cross-Section

South 73°00' East in Lat.36°46', Long.113°51'



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possible that within the proposed depths of the deep-underground cavity the gneiss may grade into granite which is intruded throughout the gneiss as dikes and irregular shaped masses. A similar situation is described under Site B, Santa Catalina Mountains.

Sedimentary Rocks. The sequence of sedimentary rocks that overlie the gneiss-granite is described under the heading Geologic Setting and is shown in Fig. 10. These rocks provide limited advantages for underground construction because of their restricted extent on the eastern flank and their occurrence over only part of the site.

Structural Features of Site

The Virgin Mountain block is characterized by a broad arch or anticline within the range. The core of the range, gneiss-granite, is an ancient pre-Cambrian rock mass that was uplifted in the Cretaceous and early Tertiary time along major boundary faults both on the west and the east. The extent of these faults is shown on the Locality Map in Figure 10. Since this initial arching and uplift, recurring movement has taken place along the boundary faults (and along other faults within), and the mountain block has been adjusted and moved several times. The most recent movement may have been during the Pliocene-Pleistocene time, or within the last one or two million years.

The gneiss-granite mass is strongly banded, and this inherent structural feature is more or less parallel to the fault zones and the trend of the folding. Within the block, strong banding occurs which dips from vertical near the crest, to 60° eastward on the west flank, and 50° west on the east flank of the range (Moore,[17]). This rock possesses an abundance of joints, fractures, and foliation planes within the near-surface zone of 1000 feet as described in Fig. 10. Below the level of 1000 to 2000 feet, the gneiss-granite is expected to be massive and fresh, with widely-spaced fractures. Undoubtedly, some moderate- to small-scale faults occur throughout the mass as anticipated from the topographic features of the site and history of similarly arched blocks of ancient rocks. For example, an abundance of such fracturing is expected near the crest of the fold, in the vicinity of Mt. Bangs, although, like the joints and small-scale fractures, any faults encountered at depths below 1000 to 2000 feet of cover are expected to be tight and to carry only limited quantities of ground water.

The axis of the broad anticline within the Virgin Mountain block trends parallel to the range, and the access tunnels are aligned perpendicular to this structure. This folding has resulted in an accentuation of the foliation and lineation structures so common to

gneiss-granite, but this inherent feature will decrease with depth.

None of the structural conditions at this site has a serious or adverse effect on the construction of a deep-underground cavity. The strong linear and foliation structures within the gneiss-granite are considered to be of minor importance in the selection of the tunnel alignment.

Although the Virgin Mountain area is considered to be seismically inactive, as evidence suggests that the mountain block may have experienced some readjustment and shifting within the past one or two million years; thus some tectonic stress may be active within this range, particularly in local areas adjacent to major fault zones.

Advantages of Proposed Tunnel Alignment

The alignment for Site B offers four major advantages:

a. The site is easily accessible from a main highway, and railroad facilities are nearby.

b. The deep-underground cavity and access tunnel are located wholly within a massive gneiss-granite rock.

c. An access tunnel of some 9000 feet attains a cover of 5000 feet for the cavity.

d. This site affords an alternate short access of 7000 feet for an underground cavity area with 4000 feet of cover.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general conditions anticipated along the proposed access alignment are shown in Fig. 10. The initial 2000 to 3000 feet of access tunnel will be driven in gneiss-granite with less than 1000 feet of cover rock. This section is expected to possess local zones of altered rock, and an abundance of joints, fractures, and foliation planes which are open and carry ground water (which will drain off). Reinforcing supports will probably be needed throughout parts of this section.

Beyond a point some 5000 feet from the portal, and where cover rock is in excess of 2000 feet, tunneling should encounter fresh, massive rock in which joints and fractures are widely-spaced, tight,

and possess only minimal amounts of ground water. Similarly, any small-to moderate-sized faults encountered at depths below 2000 feet of cover are expected to be tight and to carry only minimal quantities of water.

An alternate access tunnel alignment is shown that is some 2000 feet shorter than the lower tunnel. This alignment is portalled at an elevation of 4500 feet. Tunneling conditions along this alignment are expected to be similar to those described above for the lower access tunnel.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

Figure 10 shows two possible access tunnel locations to a potential deep-underground area beneath Mt. Bangs. Both alignments are expected to encounter the gneiss-granite throughout the entire length of the access tunnel and deep-underground cavity area. No unusual conditions are anticipated within the area of the deep cavity; ground water occurrence along fractures is expected to be minimal. The rock is expected to be fresh, massive, and of high strength. The gneiss-granite may grade into a granitic rock in the vicinity of the cavity, but this will not affect tunneling or design conditions.

Dominant Favorable Features of Deep-Underground Site

Site B includes the following desirable conditions for a deep-underground site:

a. The cover rock overlying the eastern half of the proposed cavity area consists of three or more distinct "layered" rock units which are of different physical properties (limestone, shale, sandstone). This combination of "layering" and contrasting rock types within the cover results in partial reflection of the pressure pulse due to large-scale surface or near-surface explosions. (A further explanation appears in the discussion of Mt. Washington.)

b. The tunneling conditions for both the access and the cavity area are wholly within a massive gneiss-granite of good physical properties.

c. A moderate-sized subsurface area with 5000 feet of cover is available.

d. The region of Site B was deformed by the uplift and broad arching of the Virgin Mountain block in Cretaceous and early Tertiary time and since then has been uplifted again by movement along the major faults bounding the range. As the last movement was a million or more years ago, any tectonic stress that remains within the range should be of very small to low intensity. The possibility of some areas possessing active tectonic stresses should be considered, as uplift in late Tertiary or Pleistocene time readjusted the block of Site B, and this may have developed stress concentrations that are partially retained as local "pockets".

Adverse Features of Deep-Underground Site

On the basis of knowledge available from the geologic literature and reports on this area, this site is largely free of any adverse features. Small to moderate-sized fault zones undoubtedly occur throughout the gneiss-granite block, but where encountered below depths of 2000 feet, these fault zones are expected to offer no particular tunneling difficulties. The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

NORTHWESTERN UNITED STATES

Cleveland Mountain, near Skykomish, Washington - Site A
(Township 26 North, Range 11 East)

Geographic Location and Accessibility

One access is proposed to a deep-underground cavity beneath Cleveland Mountain near Skykomish, Washington. Site A is located directly south of the main highway and the Great Northern Railroad at a point near Berlin, Washington. This site is some 40 airline miles southeast of Everett, Washington. The tunnel alignment trends S 27° W from the portal and traverses directly beneath Cleveland Peak.

Site Topography

Cleveland Mountain is the principal peak of this area, rising to an elevation of 5300 feet. The topography is steep in the area immediately surrounding the peak and flattens to gently sloping terrain on the northeast flank near the tunnel portal (see Fig. 11). The surface consists of numerous ridges and valleys carved in the volcanic rock cover and granodiorite that crops out over the site. The access tunnel alignment crosses beneath two tributary streams that flow eastward to Miller Creek and two tributary streams that flow northward to Money Creek. The topography and features of the area surrounding Cleveland Mountain are given on U. S. Geological Survey Quadrangle map, Skykomish, 1905 edition, at a scale of 1:125,000 with a contour interval of 100 feet.

Although a cover of 5000 feet is not attained until the access tunnel is nearly beneath Cleveland Peak, this site offers a large subsurface area with 5000 feet or more of cover due to the high topographic ridge that continues southward from Cleveland Peak and is outlined on the topographic map.

Geologic Setting

This site is located on the northern flank of Cleveland Mountain in an area of several rock types. Cleveland Mountain is primarily a core of granodiorite which extends to depths below the proposed access tunnel level. Overlying the intrusive granodiorite is a series of older volcanic rocks consisting of interbedded flows and volcanic breccia. This series dips northward approximately parallel to the surface profile, as shown in Fig. 11.

The Cleveland Mountain area is within the Snoqualmie granodiorite, a large batholithic mass that trends north-south through this part of Washington; the granodiorite crops out for a distance of over 15 miles in width along this belt. The Cleveland Mountain site is near the center of the batholith, as shown on the geologic map of Washington State (1961)[18]. Areal distribution of the rock units and major structural features is shown on the Locality Map in Fig. 11, after Galster, 1962[19].

Rock Units of Site

Granodiorite (Snoqualmie). The main core of Cleveland Mountain consists of a massive, medium to coarse-grained granitic rock of mid-Tertiary age, some 25 million years old. This granodiorite is a part of the major feature of this region, the Snoqualmie batholith. The relationships of the intrusive granodiorite to the overlying volcanic series and their occurrence in depth below the access tunnel are shown in Fig. 11. The granodiorite is anticipated to be in a fresh, massive, and generally high-quality condition at tunnel depths.

Volcanic Rocks. A series of andesite flows and interbedded volcanic breccia occurs as a cover on the granodiorite throughout the northern flank of Cleveland Mountain. This series, estimated to be 1000 to 1500 feet thick throughout the site area, dips northeastward at an attitude of 30° to 55°. Individual flows of andesite are massive to thin-bedded, and breccia occurs as both zones and beds throughout the series. As no detailed geologic work has been undertaken on this series in the vicinity of Cleveland Mountain, the relative proportions of andesite and breccia are unknown. The volcanic series consists of rocks of Eocene-Oligocene age (over 25 million years old).

The volcanic series caps Cleveland Peak, and the contact with granodiorite is some 2000 feet south of the peak. The portal of Site A is collared in the volcanic rock series near the point where these rocks dip below the surface and are concealed by the stream alluvium and glacial debris of the Skykomish River valley. The physical condition of the volcanic series and the anticipated tunneling conditions are given in Fig. 11 and below.

Structural Features of Site

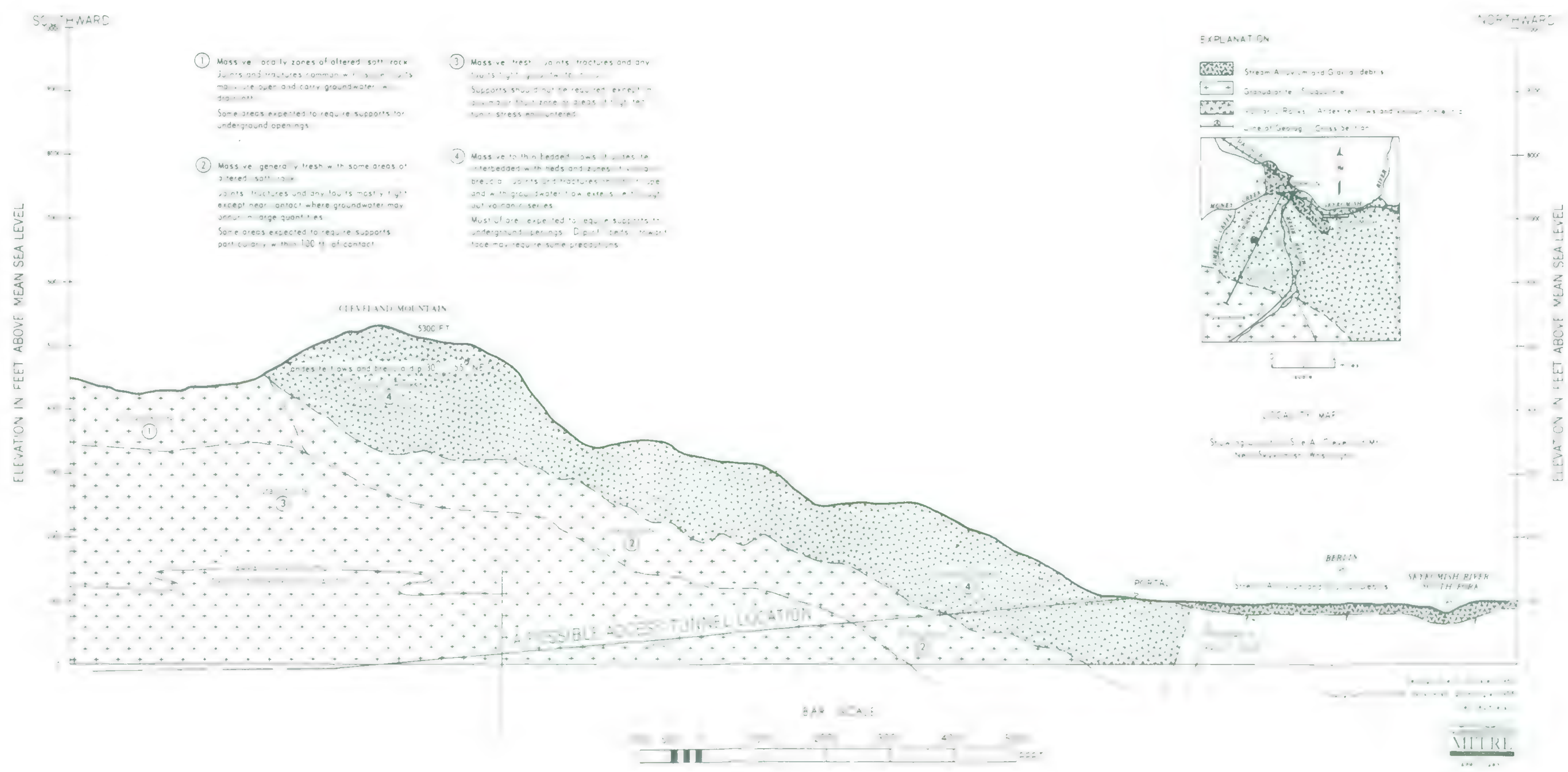
The Cleveland Mountain area is a "domal" uplift within the wide regional belt of the Snoqualmie batholith. The principal structural feature of this site is the "domal" outline of the

Fig. 11

CLEVELAND MOUNTAIN
NEAR SKYKOMISH, WASHINGTON Site A

Looking Northwestward **along** Geologic Cross-Section

North 27°00′ East in T. 26N., R.11E



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granodiorite and the overlying series of volcanics that dip northeastward. A large fault zone occurs along the eastern margin of Cleveland Mountain within the valley of Miller Creek. This fault zone crosses the tunnel alignment a short distance north of the proposed portal.

Undoubtedly, moderate- to small-scale faults occur throughout the series of volcanic rocks and within the granodiorite mass. The occurrence and extent of these features are estimated from topography only, as no detailed geologic map of this site has been prepared.

Areally, Site A is located within a large block bounded by the "Miller Creek" fault on the east, and a continuation of it to the northwest along the valley of the Skykomish River. A second large fault zone occurs some two miles south of Cleveland Peak, and large faults are known to occur several miles west of the site. The rock units are mildly deformed due to the igneous intrusion of the granodiorite and the doming effect which tilted the overlying volcanic rocks to the northeast. Within the granodiorite, a rude lineation structure is expected, consistent with the pattern of such large granitic rock bodies. (Its effects on tunneling and design are described under Site A, Santa Catalina Mountains.)

None of the structural conditions at this site adversely affects the deep-underground cavity, Site A.

The volcanic rocks traversed by the access tunnel are expected to dip 30° to 55° northeast into the tunnel opening. This attitude of the bedding and rock units will require special consideration in driving the tunnel. Of particular significance is the possibility of excessive ground water circulation along the bedding planes and the interconnected joint system of the andesite flows, as well as along the zones of volcanic breccia. The attitude of the volcanics on the northern slope of Cleveland Mountain will allow recharge infiltration on the high slopes to migrate down the dip, and consequently a large amount of ground water may occur throughout the volcanic series as shown in Fig. 11. This "reservoir" of water is limited in extent by the outcrop of volcanic rocks, and it will drain off to an amount equal to the recharge.

The contact between the volcanic rocks and the underlying granodiorite may be broken and somewhat weathered to depths of tens of feet. This condition, plus the further likelihood that either this contact or the basal zone of the volcanics may afford strong ground water circulation, requires that caution be exercised

when tunneling through this sector of the access alignment. (The ground water involved will drain off to minimal amounts.)

The area, although generally considered to be seismically inactive, may experience seismic events. Washington State is seismically active along the Pacific Coast; the Snoqualmie batholith is on the eastern margin of this active belt. Some consideration is warranted for the possibility of earthquake activity at this site.

Advantages of Proposed Tunnel Alignment

The alignment for Site A offers three major advantages:

a. The site is easily accessible, and the portal is located within a short distance of a major highway and railroad.

b. Sufficient topographic relief is available to attain a cover thickness of 5000 feet within an access tunnel length of 10,000 feet.

c. The deep-underground cavity is located within a uniform, massive, granitic rock.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general condition of the rock types encountered along the access tunnel alignment is shown in Fig. 11. Within the near-surface zone of 1000 to 2000 feet, both the volcanic rocks and granodiorite are expected to possess joints and fractures in abundance, particularly the volcanics. Weathering has deteriorated the rocks somewhat within this zone as delineated and described in Fig. 11. The physical properties of the volcanic rocks are fair to poor in comparison to the good quality of the granodiorite.

The portal is collared in volcanic rock, and this series is traversed for some 3000 feet along the access tunnel. Conditions anticipated within the volcanic series have been described under the heading Rock Units of Site. Of particular concern within this section of the tunnel are:

1. the attitude of the volcanic beds which dip eastward or into the tunnel

2. the relative proportion of volcanic breccia within this series, with particular concern for the type of cementing or the manner in which the breccia is "welded" together, since this rock may prove very unstable; and

3. the likelihood of encountering large quantities of ground water as described earlier (also see the discussion of this zone in Fig. 11).

The contact between the volcanic rocks and the underlying intrusive granodiorite was described under the heading Rock Units of Site. The tunnel may encounter some fractured and deteriorated rock carrying large quantities of ground water within the area of this contact. Beyond the immediate contact zone, the granodiorite may be extensively fractured and partially weathered to depths of a few hundred feet (this band is shown in Fig. 11). Beyond this sector of the access tunnel, rock conditions are expected to be excellent. An occasional fault zone may be encountered within the granodiorite mass. Below depths of 1000 to 2000 feet of cover, however, these fault zones and widely-spaced joints should be tight with ground water present in small quantities or absent.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

The rock within the vicinity of the proposed deep-underground cavity at Site A (4500 to 5100 feet of cover) is a massive, medium-grained granodiorite. This rock is expected to be strong and durable and should possess good engineering properties for underground construction. Joints, fractures and faults, where present, should be widely-spaced and tight, having only minor influence on the design and tunneling conditions. No appreciable quantities of ground water are expected at the level of the cavity. Requirements for supports and reinforcement within the cavity area will be directly related to the size of the underground openings constructed.

Some tectonic stress may be active at this site. Supports should not be required on an average-size access tunnel, except in fault zones or areas of high tectonic stress.

Dominant Favorable Features of Deep-Underground Site

Site A beneath Cleveland Mountain includes the following desirable conditions for a deep-underground site:

a. The cover rock overlying the proposed cavity area consists of two or more distinct and "layered" rock units — the interbedded volcanics and breccia overlying the modified granodiorite contact which grades into the cavity rock. This condition of "layering" and contrasting rock types within the cover results in partial reflection of the pressure pulse due to large-scale surface or near-surface explosions (see discussion of Mt. Washington).

b. The granodiorite host for the deep cavity is a massive, strong, high-quality rock for underground construction.

c. The region of Site A was deformed during mid-Tertiary time. The volcanic series (Eocene-Oligocene age) was intruded by the younger Snoqualmie granodiorite some 25 million years ago. Consequently, the tectonic stresses associated with the mountain-building and uplifting of Cleveland Mountain area have partially decayed and perhaps have been largely relieved. The amount of latent tectonic stress remaining and active at this site is unknown, and should be investigated.

Adverse Features of Deep-Underground Site

Conditions encountered throughout the volcanic series at this site may cause some tunneling difficulties; the weak rock conditions, creep (aided by the dip of beds), and ground water inflow are possibilities.

In order to avoid tunneling through the volcanic rocks, the access tunnel portal could be located on the eastern edge of Mt. Cleveland, south of granodiorite contact, in the valley of Miller Creek (see the Locality Map in Fig. 11). Although this portal location would not afford as thick a cover rock beneath Cleveland Peak as at Site A, due to the shorter inclined tunnel and higher portal elevation, the additional advantages of the "layered" cover at Cleveland Mountain could offset the reduced thickness of the total rock column overlying an underground cavity accessible via this alternate portal.

Mountain along Icicle Creek, near Leavenworth, Washington - Site A
(Township 24 North, Range 17 East)

Geographic Location and Accessibility

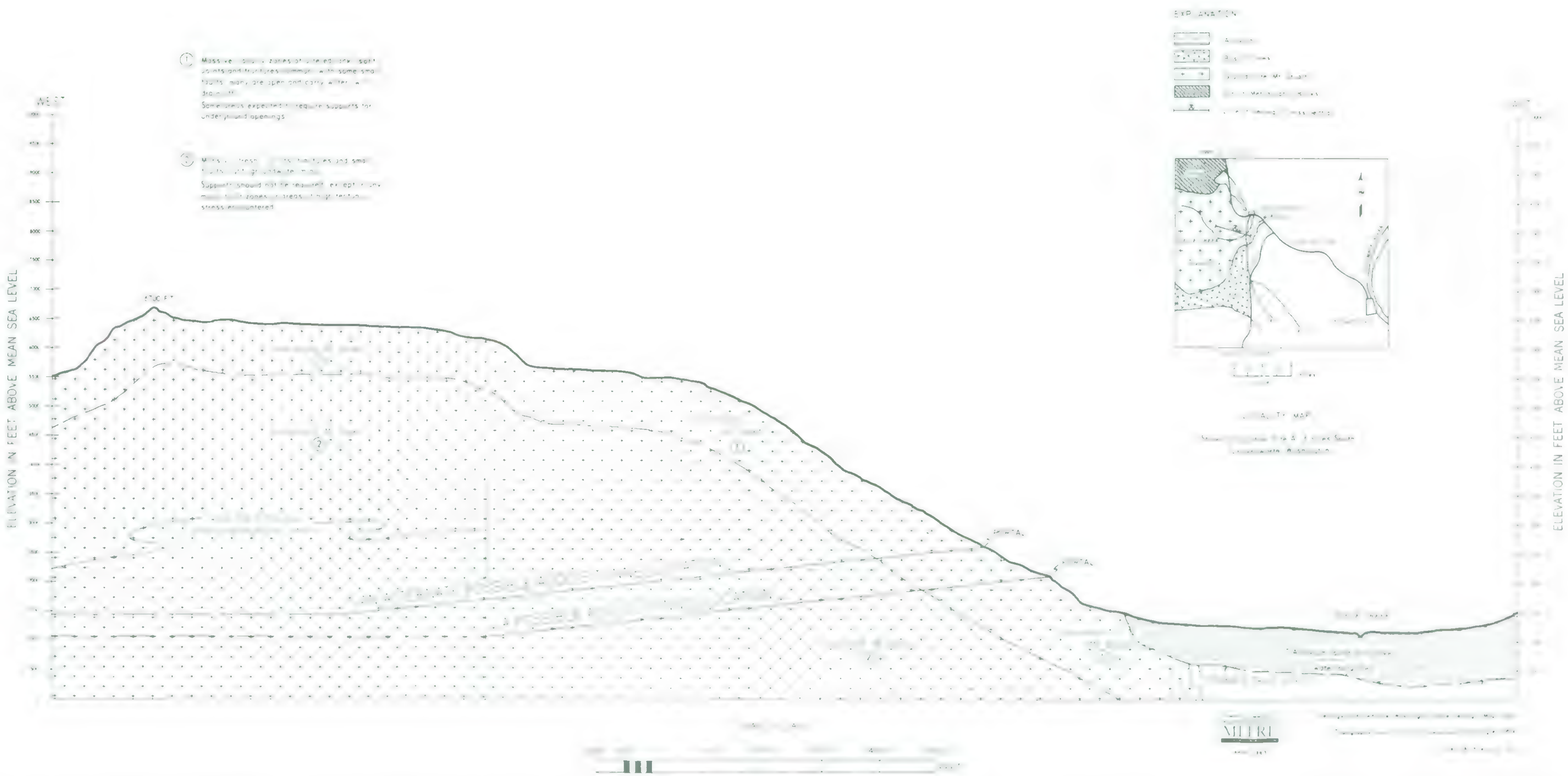
A deep-underground site is proposed beneath a mountain along Icicle Creek south of Leavenworth, Washington. Two alternate portal locations are shown in Fig. 12 along the same alignment beneath this mountain. Site A is located three miles south of Leavenworth, a small town on the Great Northern Railroad and the main highway between Wenatchee and Everett, Washington. Leavenworth is located some 20 miles northwest of Wenatchee. This site alignment trends N 75° W and traverses directly beneath the main peak.

Fig. 12

MOUNTAIN ALONG ICICLE CREEK, SOUTH OF LEAVENWORTH, WASHINGTON Site A

Looking Northward along Geologic Cross-Section

North 75°00′ West in T.24N,R.17E



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Site Topography

The principal peak along Icicle Creek rises to a height of some 6700 feet from the flat valley of the Wenatchee River, of less than 2000 feet elevation. The topography is steep on the eastern slopes of this peak; the upper part is rather flat (see Fig. 12) and represents an ancient erosion surface of the region back in Pliocene time (1 to 11 million years ago). The surface of the site consists of similar steep slopes on the southern margin, with steep ridges and intervening canyons on the northern flank. The access tunnel alignment is located to avoid traversing beneath any of the tributary streams flowing off the north slope. A small lake is located about 1500 feet north of the tunnel alignment near the crest of this mountain. The topography and features of the area surrounding this site are given on U. S. Geological Survey Quadrangle map, Chiwaukum, 1904 edition, at a scale of 1:125,000, with a contour interval of 100 feet.

Icicle Creek and the tributaries of the Wenatchee River are perennial streams and recharge ground water to the subsurface throughout the area of the site.

A cover of 5000 feet is attained beneath this site by either of the alternate access tunnels shown in Fig. 12. This site offers a very large subsurface area with 5000 feet or more of cover within good-quality granodiorite rock. The proposed access alignments take advantage of this large underground potential with the access alignment parallel to the "flat-topped" ridge of the mountain.

Geologic Setting

This site is located on the eastern flank of the main peak in the area of Icicle Creek. Granodiorite (Mt. Stuart) crops out over the site and is the only rock within the area of the alignment and proposed deep-underground cavity.

The site rock is part of the regional mass of the Mt. Stuart granodiorite, which crops out over a wide belt in central Washington, and is over 20 miles wide near the site. The Mt. Stuart batholith of granodiorite is bounded on the south and west by major fault zones and on the northeast in the vicinity of Leavenworth by a similar fault zone. Remnants of the ancient volcanics and metamorphic rocks that pre-date the batholith occur as patches overlying the Mt. Stuart granodiorite in this region. The typical relationship of the granodiorite to these rocks is shown on the Locality Map in Fig. 12, where schist occurs directly north of Site A. A younger (post-granodiorite) basalt crops out within a short distance south of Site A.

The region was glaciated in Pleistocene time, and glacial debris occurs intermixed with younger alluvium in the valley of Icicle Creek and the Wenatchee River.

Rock Units of Site

Granodiorite (Mt. Stuart). The site of the mountain along Icicle Creek consists wholly of a massive, medium to coarse-grained granodiorite (Mt. Stuart). Locally, the rock varies markedly in grain size and color, but this has little effect on its gross physical properties. The site rock is part of a major batholithic feature of this part of Washington State (map of Washington, 1961[18] The granodiorite mass extends to depths well below the proposed access tunnel levels. This intrusive rock is anticipated to be in a fresh, massive and generally high-quality condition at tunnel depths except near the portal.

Structural Features of Site

The Icicle Creek site is part of a broad domal uplift within the Mt. Stuart batholithic mass. The principal structural feature of this site is the strong fault zone that traverses nearly north-south along the eastern edge of the site, as shown on the Locality Map and cross-section in Fig. 12. Either of the alternate portal locations avoids intersecting this fault zone

Undoubtedly, moderate- to small-scale faults occur throughout the granodiorite. The occurrence of these features is inferred from the topography, but, as this site has not been mapped in detail, the location and extent are unknown. The granodiorite probably also possesses a rude lineation pattern common to large granitic masses of this type. The causes of the linear structures and their possible effects on tunneling conditions are discussed in the sections on Mt. Washington and Whiteface Mountain.

Areally, Site A is located within a large block bounded on the east by a major fault, and on the northeast and on the west at a distance of 20 miles by similar fault zones. Undoubtedly, the whole mass of Mt. Stuart granodiorite has been uplifted as a block, and then blocks within the mass have been moved; this shifting between blocks probably took place at intervals throughout the geologic history of Tertiary time (up to one million years ago).

None of the structural conditions at this site is of adverse effect to the proposed alignment, Site A.

The area, although generally considered to be seismically inactive, may experience seismic events. The main seismic activity in Washington State occurs within the belt west of the Snoqualmie batholith and through the Puget Sound region. Some consideration is warranted however, at this site for the possibility of earthquake effects.

Advantages of Proposed Tunnel Alignment

The alignment for Site A offers the following four major advantages:

a. The site is easily accessible and has a portal location within a short distance of both a major highway and railroad.

b. Sufficient topographic relief is available to attain a cover thickness of 5000 feet within an access tunnel length of 9000 feet.

c. The deep-underground cavity is within a uniform, massive, granitic rock.

d. A very large subsurface area with 5000 feet of cover is available at this site.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The principal rock conditions anticipated along the alternate access tunnel alignments are described in Fig. 12. This includes an estimate of the areas that may require reinforcing and supports for underground openings, which are largely restricted to the near-surface 1000 to 2000 feet of granodiorite. Some fault zones may be encountered along the access tunnel, although at depths below 1000 to 2000 feet of cover, they are expected to be tight and offer minimum tunneling difficulties. Furthermore, such faults are expected to carry only minimal amounts of ground water at depths below the near-surface zone described in Fig. 12. Joints and fractures are widely-spaced in the areas of deep cover and should offer no particular tunneling difficulties.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

Figure 12 shows two possible alignments for an access tunnel beneath Site A. Both alignments are expected to encounter similar rocks along their access and within the area of the potential deep-underground cavity. No unusual conditions are anticipated

within the area of the deep cavity; ground water occurrence along fractures is expected to be minimal. Requirements for supports and reinforcement within the cavity area will be directly related to the size of the underground openings constructed.

Any areas of active tectonic stress which may be encountered are expected to be of moderate to low intensity. Supports should not be required on an average-size access tunnel except in fault zones or areas of high tectonic stress.

Dominant Favorable Features of Deep-Underground Site

Site A beneath the mountain along Icicle Creek includes the following desirable conditions for a deep-underground site:

a. The tunneling conditions in both the access and cavity areas are within a massive, uniform, and consistent rock type.

b. A large subsurface area with 5000 feet of cover is available.

c. The region of Site A was deformed in ancient geologic time (Mesozoic) and since then has been rather stable, so that the granodiorite mass itself has not been affected by deformation and active tectonic stress in recent geologic time. Consequently, tectonic stresses have had an opportunity to be dissipated. The amount of this decay is unknown, however, and some tectonic stress may occur at this site. This possibility should be considered during the exploration stages.

Adverse Features of Deep-Underground Site

On the basis of knowledge available from the geologic literature and reports on this area, this site is largely free of any adverse features. The major fault zone that traverses the site on the eastern margin is the only condition likely to affect construction. As its exact location is unknown (as noted on the cross-section of Fig. 12), this fault zone may occur quite near the portal locations for the proposed access tunnels and could affect their location.

ALASKA

Chugach Mountains, near Chickaloon, Alaska - Site A
(Township 19-20 North, Range 6 East
Latitude 61° 46', Longitude 148° 18')

Geographic Location and Accessibility

A deep-underground site is proposed beneath the Chugach Mountains, Upper Matanuska Valley, Alaska. The tunnel alignment suggested, Site A, portals on the northern edge of the Chugach Mountains and trends S 23° E to a point beneath the main peak as shown on the Locality Map in Fig. 13.

The portal of Site A is located about one mile south of the Glenn Highway and across the Matanuska River at a point some 83 miles west of Anchorage, Alaska (Milepost 83). The portal of Site A is also accessible via the Glenn Highway to the Richardson Highway located some 107 miles east of the site. A spur track of the Alaska Railroad to the coal mining community of Chickaloon has been abandoned for many years.

Site Topography

The area of the Chugach Mountains is steep in terrain due to the abundance of small canyons and ravines that are carved on the flanks of the main mountain mass. The topographic relationships of the site are shown in Fig. 13. This alignment has been chosen to follow beneath a prominent ridge that trends northward within the granodiorite mass and thereby provides maximum cover throughout the access tunnel location. The portal of Site A is located at an elevation of some 1350 feet within the gently sloping terrain of the river valley. The topography rises abruptly south of the portal to an elevation of 5484 feet at the main peak of Site A, within a distance of 11,000 feet.

The topography and features of the area surrounding this site are given on U. S. Geological Survey Quadrangle map, Anchorage (D-4), Alaska, 1952 edition, at a scale of 1:63,360 with a contour interval of 1000 feet. The topography is also given by Capps and Mertie (1927).[21]

Many perennial streams headwater on the slopes of the Chugach Mountains and flow northward to the Matanuska River (see Fig. 13). The access tunnel of Site A avoids traversing beneath any of these streams by its alignment along the major ridge.

The access tunnel attains a cover of 5000 feet or rock within some 10,000 feet of tunnel. Site A offers excellent underground potential, having a large subsurface area with 5000 feet or more of cover rock.

Geologic Setting

This site is located on the southern edge of the extensively faulted and complexly deformed series of rocks that comprise the Matanuska Valley. The Chugach Mountains that border the valley on the south are a large fault block bounded by a major fault zone on the north. The areal distribution of the principal rock types is shown on the Locality Map in Fig. 13. The underground site is in the large granodiorite mass of the mountains, which is in fault contact with volcanic rocks. A series of shale and sandstone beds crop out north of the volcanics, but are largely concealed by glacial debris and alluvium at the site. The sandstone and shale series is tilted steeply to the south, and the volcanic rocks are deformed and highly sheared. Both of these rock units were faulted and folded during the numerous structural events that accompanied development of the Matanuska Valley.

Rock Units of Site

Granodiorite. The principal rock type encountered along the alignment of Site A and the locality for the proposed deep-underground cavity is a mass of granodiorite formed in the late Jurassic age some 135 million or more years ago. This granitic rock is part of a large outcrop within the Chugach Mountains that extends for several miles along the southern margin of the Matanuska Valley. The granodiorite was intruded into the older volcanic rocks, and this contact, which is expected to be broken and crushed, represents a major fault zone that bounds the Matanuska Valley.

The granodiorite is variable in composition, ranging from a diorite to a quartz diorite; locally it is extremely coarse-grained to porphyritic in texture[21]. This variation in texture and mineral composition does not affect the physical properties of the rock enough to concern underground construction. The granodiorite is anticipated to be in a fresh, massive, and generally high-quality condition at tunnel depths below 2000 feet of cover (see the description in Fig. 13).

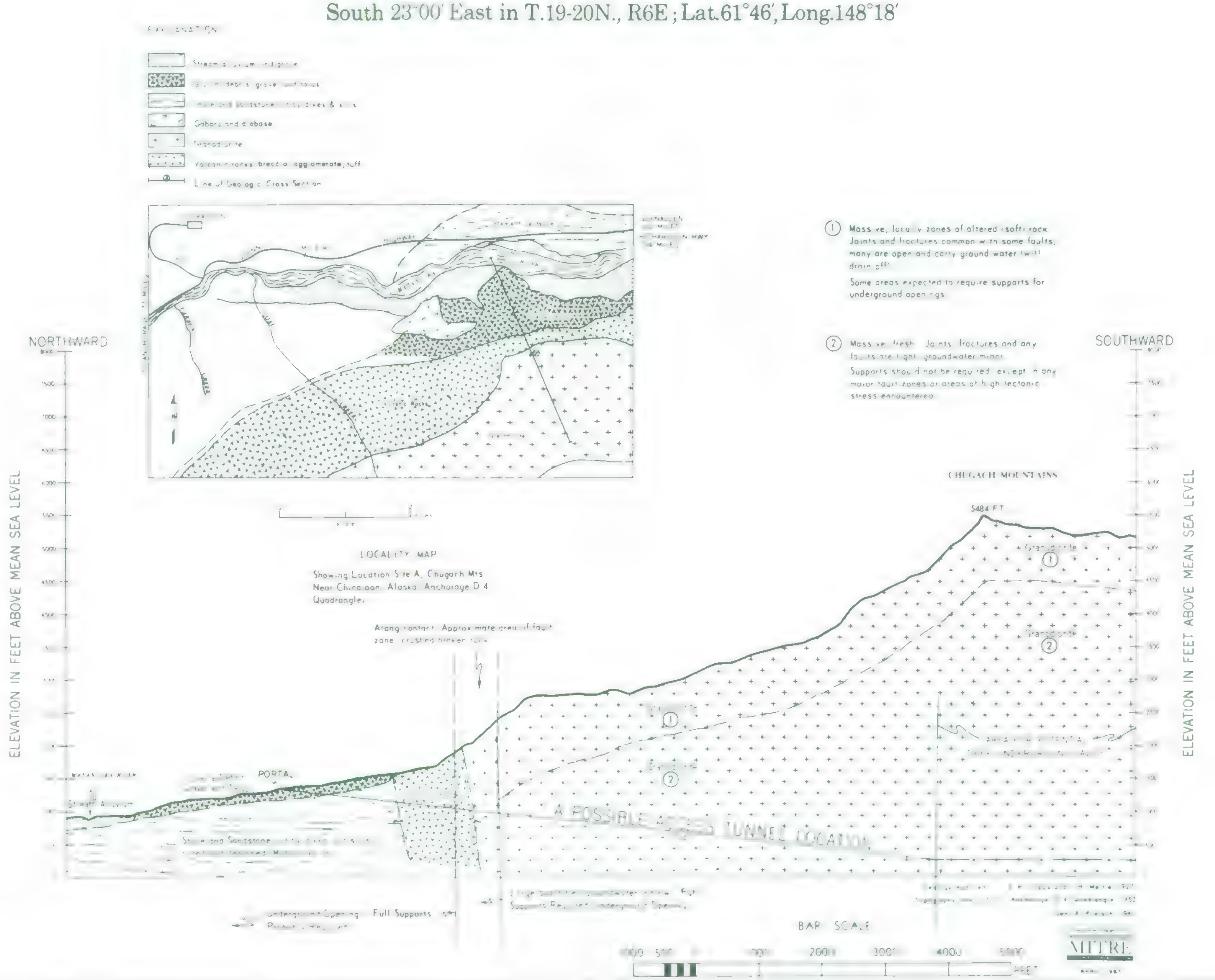
Volcanic Rocks. A thick series of volcanic rocks formed in the early Jurassic age and pre-dating the granodiorite occurs along the northern edge of the Chugach Mountains. The volcanics

Fig. 13

CHUGACH MOUNTAINS, NEAR CHICALOON, ALASKA Site A

Looking Eastward along Geologic Cross-Section

South 23°00' East in T.19-20N., R6E; Lat.61°46', Long.148°18'



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(Talkeetna formation) consist of an interbedded series of basalt and andesite flows, agglomerate (coarse to cobble-sized fragments), volcanic breccia, and thin to thick beds of tuff and tuffaceous sandstone. The volcanic rocks, which are irregular in their physical properties, may vary from dense lava flows to coarse, angular, extremely porous breccia and agglomerate beds. The tuff beds are expected to be a soft and physically weak rock for tunneling. Most of the volcanic rocks have been faulted, sheared, and softened by alteration.

Boundaries and contacts of the volcanic rock series are expected to be broken due to faulting, particularly near the granodiorite mass. This latter zone is expected to be quite broken and to contain large quantities of ground water. Underground openings are expected to require full support, and caution should be exercised in tunneling within the volcanic series. The contact between the tilted shale and sandstone series (Matanuska formation) and the volcanic series may be broken due to extensive fault movement.

No subsurface exploration data are available at this site, and a full explanation of the anticipated conditions is impossible. If, however, this site is explored for the design of an underground cavity, particular attention should be given to the subsurface conditions of the volcanic rocks and their contact features with both the sandstone and shale on the north and the granodiorite on the south.

Sandstone and Shale. An alternating series of thin to thick sandstone and shale beds (Matanuska formation) crop out along the northern edge of the volcanic series. These beds have been tilted southward and deformed during the progressive block faulting that developed the Matanuska Valley structure. Subsequently, these rocks were invaded by dikes and sills of gabbro and diabase in Pliocene time over one million years ago. Although the dikes and sills are most frequent within the shale beds of this series, they occur along bedding planes of the sandstone and may occur near the contact with the volcanic series. The contact relationships with the volcanic rocks on the south have been described under the previous heading.

Among the difficulties which may be encountered in tunneling through the section of shale and sandstone, the following are of particular importance:

a. The dip of the beds is southward, away from the tunnel heading.

b. A strong groundwater flow is expected within the sandstone beds and may occur throughout the fractured dikes and sills but will diminish as the water table is lowered by the free draining.

c. Neither the sandstone nor the shale is expected to be a strong, durable rock and undoubtedly both will require supports and reinforcing.

Glacial Debris, Gravel, and Talus. Overlying the sandstone and shale series throughout the portal area, Site A, is a thick blanket of glacial debris ranging in size from gravel and boulders to angular talus blocks. The depth of this surficial cover is unknown, but areal relationships indicate it may be up to 100 feet thick. This surface blanket is expected to contain large quantities of ground water charged by the numerous streams that flow across the outcrop from the flanks of the Chugach Mountains.

Tunneling conditions within the surficial cover will require full supports. After determining the depth of the glacial debris, it may prove advisable to use an open cut through the glacial debris and locate the access tunnel portal in the underlying shale and sandstone rocks.

Gabbro and Diabase. A large outcrop of the young gabbro and diabase occurs less than 1000 feet west of the tunnel alignment. These rocks are related to the gabbro and diabase sills and dikes described as being common within the sandstone and shale series (Matanuska formation). The gabbro, a coarse to medium-grained rock, possesses good qualities for tunneling purposes. The diabase is a medium to fine-grained rock and should prove similar in characteristics to the gabbro. These rocks were emplaced after the main structural events that formed Matanuska Valley and are believed to be associated with volcanic activity that occurred during Pliocene time over one million years ago.

Structural Features of Site

The principal feature controlling the present topography and distribution of rocks throughout the area is the down-dropped structural block of the Matanuska Valley. The valley, a small part of which is shown on Locality Map in Fig. 13, is bounded on the north by a major mountain range, the Talkeetna Mountains, and on the south by the Chugach Mountains, in which Site A is located. The Matanuska Valley trends westward in the area of Site A, but changes to a southwestward trend near Chickaloon and continues in this direction to the Cook Inlet lowlands near Anchorage.

The Chugach Mountains are composed of metamorphic rocks with numerous large granitic intrusives such as that at Site A on the Locality Map in Fig. 13. The Matanuska Valley area is bounded by major fault zones roughly parallel to the river; on the north, the fault zones occur within the Talkeetna Mountains, beyond the limits of the Locality Map. On the south, the major fault zones are within or bound the Chugach Mountains; one of these fault zones traverses Site A. The sedimentary, volcanic, and igneous rocks within the valley block are complexly folded and faulted due to several periods of displacement and deformation that formed the Matanuska Valley structure. There is no uniform trend to the rock units within the vicinity of Site A. Generally, the sedimentary shale and sandstone series dips steeply southward, or into the tunnel site. The volcanic rock series also is believed to dip steeply southward although the evidence for this is sketchy. The contacts between the three rock types encountered along the site alignment (sediments, volcanics, granodiorite) are expected to contain broken rocks and fault zones, as shown in Fig. 13.

Areally, Site A is on the margin of the Matanuska Valley block and within adjoining fault blocks although the underground cavity is wholly within one block. Deformation has occurred throughout the valley at intervals during Tertiary time, and this has resulted in the progressive erosion and scouring out of the Matanuska Valley.

The major fault zones described above are important in selecting the general location of an access tunnel and area for a deep-underground cavity. The major fault zone shown on existing maps is traversed by the tunnel near its portal, but the main site for a deep cavity is little affected by this feature. Undoubtedly, numerous small-scale faults, fractures and joints occur throughout the granodiorite mass, although they are not shown on existing geologic maps. These features are expected to be tight, however, and to carry minimal amounts of ground water where they are encountered at depths below 2000 feet of cover.

Although seismic activity has not been reported from the vicinity of Site A, the abundance of major fault zones and the progressive deformation of the valley area since Miocene time less than 25 million years ago suggest that some readjustment along these faults could occur in the future. Of importance to the underground site is the possibility that some active tectonic stress may exist within the granodiorite mass of Site A. This possibility should be investigated during the exploration of this site.

Advantages of Proposed Tunnel Alignment

Within this part of Alaska, there seems to be a scarcity of potential sites in granitic rock which meet topographic requirements and are readily accessible. Although Site A is some 83 miles from Anchorage, it offers several advantages:

a. The portal is easily accessible from the Glenn Highway.

b. Sufficient topographic relief is available to provide a cover thickness of 5000 feet within an access tunnel length of some 10,000 feet.

c. The deep-underground cavity and most of the access tunnel are located within a massive granitic rock.

d. A large subsurface area is available with a cover of 5000 feet.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general conditions anticipated along the proposed alignment are shown in Fig. 13. Within the first 3000 feet of the access tunnel, rock conditions are poor, in contrast to the remainder of the access and the deep underground site. The portal is located in glacial debris, sand, and gravel which may extend to 100 feet in depth. Beneath this surficial cover, a series of shale and sandstone beds is traversed by the tunnel alignment for a distance of some 1000 feet. These shale and sandstone beds are expected to vary in their physical properties, and probably dikes and sills of gabbro and/or diabase will be encountered. This series of shale and sandstone is believed to dip steeply southward, or away from the tunnel heading. Ground water will be encountered, particularly in the sandstone beds and in the fractured dikes and sills throughout this sector of the tunnel. The inflow of ground water will be enhanced by the alluvial cover which is expected to be largely saturated with ground water. Small faults, fractures, and broken rock are anticipated within the shale and sandstone series. This section of the access tunnel will probably require full support for the underground opening.

Beyond the shale and sandstone series, at a point some 1600 feet from the portal, the tunnel alignment traverses approximately 1100 feet of volcanic rocks. These rocks are anticipated to be weak, highly broken, and porous, and to contain large quantities of ground water. The contacts of the individual volcanic rock units are expected to be faulted and broken, particularly on the

south along the margins of the granodiorite mass. The broken area of the fault zone is shown in Fig. 13. Full support will probably be required throughout the section of volcanic rocks, and particular attention will be required in the area near the fault zone and contact with the granodiorite.

After traversing the granodiorite contact and marginal structural features of this rock mass, the tunnel should meet improved conditions within a short distance; at a point some 3500 feet from the portal, the granodiorite rock is expected to be fresh, strong, and of good quality for the access tunnel opening. No particular difficulties are anticipated throughout the remainder of the access tunnel alignment. The tunnel may require supports throughout any fault zones encountered. Minimal quantities of ground water are expected at depths below 2000 feet of cover.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

The area of a potential deep-underground cavity shown in Fig. 13 is wholly within the granodiorite mass of the Chugach Mountains. No unusual conditions are anticipated within the area of the potential deep cavity. The granodiorite is expected to be massive and fresh, with high strength and good physical properties.

Supports should not be required on an average-size access tunnel except in any fault zones or areas of high tectonic stress which are encountered. The requirements for supports and reinforcement within the cavity area will be directly related to the size of the underground openings constructed.

Dominant Favorable Features of Deep-Underground Site

Site A includes the following desirable conditions for a deep-underground site:

a. Most of the access tunnel alignment and the cavity area lies within a massive, uniform, granitic rock.

b. A large subsurface area with 5000 feet of cover is available. The length of the access tunnel is some 10,000 feet.

c. The region of Site A was initially deformed by the emplacement of the granodiorite in ancient geologic time (Mesozoic) and since then has been unlifted by several separate structural events. Each of these movements resulted in large blocks being displaced,

and subsequently, the down-faulted block of the Matanuska Valley was developed. Since fault displacement occurred recently, throughout Tertiary time, a readjustment along some fault zones could occur in the future. This geologic history suggests that some tectonic stress may remain within the granodiorite mass, although this should be of low intensity. The possibility of some areas possessing active tectonic stresses should, however, be considered.

Adverse Features of Deep-Underground Site

This site possesses excellent topographic relief and deep-underground conditions for a cavity. No major adverse features are known within the immediate vicinity of the deep cavity area.

The access portal conditions within the first 3500 feet of the tunnel are average to poor in comparison with those of a massive granitic rock. Although the conditions described may appear serious, exploration at this site may determine that the physical properties of the rock units and the structural features described are less adverse than suggested by the information available. No subsurface data have been collected at this site. Certainly, before this site is given serious consideration, some exploration must be performed within that area traversed by the access tunnel before it encounters good-quality granodiorite some 3500 feet from portal.

Granite Mountain, Big Delta Region, Alaska - Site A (Latitude 63° 46', Longitude 145° 16')

Geographic Location and Accessibility

A deep-underground site is proposed beneath Granite Mountain, Big Delta region, Alaska. Two separate access alignments are suggested, Site A and Site B. Site A portals on the northeastern edge of Granite Mountain and trends S 61° W to a point beneath the main core of the granite mass. The areal setting of Site A is shown on the Locality Map in Fig. 14.

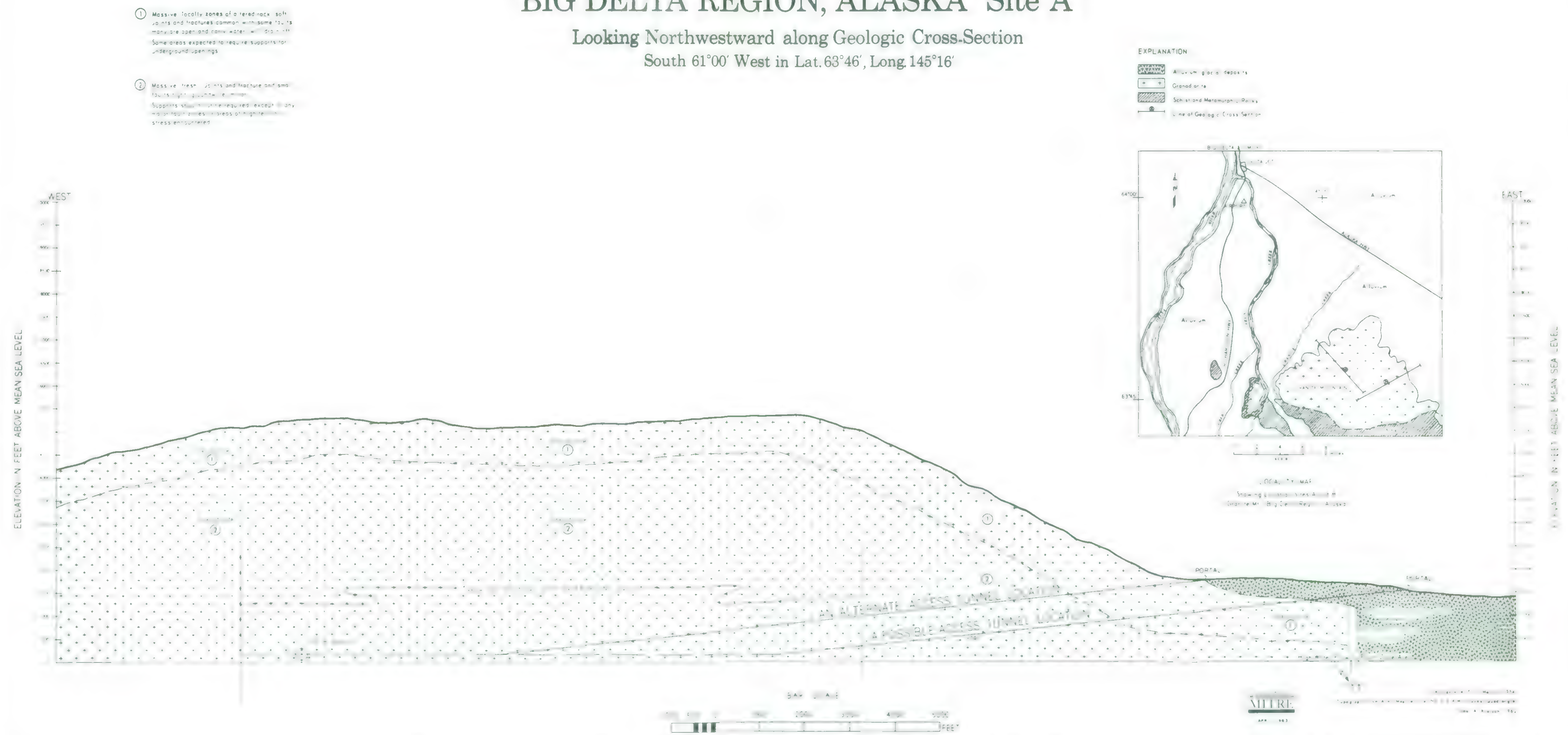
Site A is located some six miles south of the Alaskan Highway, accessible over flat, alluvial terrain. The site is some 25 miles south of Big Delta, Alaska, by highway and access road. Delta Junction is 18 miles northwest by the same route and the Alaskan Highway; airport facilities are also available.

Fig. 14

GRANITE MOUNTAIN
BIG DELTA REGION, ALASKA Site A

Looking Northwestward along Geologic Cross-Section

South 61°00′ West in Lat. 63°46′, Long. 145°16′



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Site Topography

The area of Granite Mountain is steep in terrain due to the numerous small canyons and ravines that have been carved on the flanks of the broad granite mountain. The barren rock surface rises on a moderate slope from the flat, alluvial-covered valley of the Gerstle River to a flat-topped mountain, as shown in Fig. 14. The flat cap on Granite Mountain probably represents an ancient erosion surface of the region. The topography and features of the area surrounding Granite Mountain are given on Army Map Service NP 5, 6-4 Mt. Hayes Quadrangle, at a scale of 1:250,000, with a contour interval of 200 feet.

Several perennial streams headwater near the crest of Granite Mountain and flow to the drainage of Gerstle River on the east and Jarvis Creek on the west of the mountain.

The access tunnel alignment, Site A, follows beneath the main flat-topped ridge of Granite Mountain. This access is the shortest possible tunnel alignment to attain a rock cover of 5000 feet.

Site A offers excellent underground potential, having an extremely large subsurface area with 5000 feet or more of cover rock.

Geologic Setting

This site is located on the northeastern part of the Granite Mountain area, which is roughly circular and is some 12 miles wide. The massive granite body is bounded on the south by a series of metamorphic rocks, primarily schist with some gneiss, as shown on the Locality Map in Fig. 14. The principal physical feature of the Granite Mountain is that of a broad "domal" uplift due to the intrusion of the granodiorite rock into the schist and gneiss series. Major fault zones bound the granite mass as described below under the heading Structural Features of Site. Both Sites A and B are wholly within the granodiorite mass of Granite Mountain.

Rock Units of Site

Granodiorite. Granite Mountain consists of massive, coarse-grained granodiorite of Mesozoic age (Jurassic-Cretaceous), i.e. 70 million to over 135 million years old. The granitic rock is part of a large batholithic mass that crops out throughout this general region of Alaska. The relationship of the granodiorite

to the older schist and gneiss is typical of intrusives. This contact of these two rock types may be highly broken, fractured and altered, but this contact zone is not encountered within either site suggested.

The granodiorite is anticipated to be in a fresh, massive, and generally high-quality condition at tunnel depths (see the description in Fig. 14). The granodiorite varies in mineral composition from diorite to quartz diorite and locally is extremely coarse to porphyritic in texture (Moffit, 1954[22]). This variation does not affect the strength and properties of this rock for underground construction.

Structural Features of Site

The Granite Mountain area is a domal uplift within a wide batholithic belt of Mesozoic granodiorite. The principal structural feature of this site is the domal outline of the granodiorite, as expected from the manner in which it was intruded into the host rock and subsequently uplifted along marginal fault zones. A major fault zone is anticipated on the northeastern margin of the Granite Mountain area,(although it is not shown on the geologic map by Moffit, 1954[22]). The approximate position of this probable fault zone is shown in Fig. 14 and although its exact location is concealed by the overlying blanket of alluvium that extends outward from the toe of the granodiorite slope. The proposed access alignment, Site A, is portaled in the overlying alluvium in order to attain a minimum cover depth of 5000 feet within some 12,000 feet of access tunnel.

Undoubtedly, moderate- to small-scale faults occur throughout the granodiorite mass, as anticipated from the topographic features and history of similar intrusive rocks. A detailed geologic map of this area has not been prepared.

Areally, Site A is located within a large block up to 12 miles in width which is bounded by a major fault zone on the northeast, the southwest, and the northwest, and by the intrusive contact with metamorphic rocks on the southern boundary. It is probable that the granodiorite mass was mildly deformed during intrusion and now possesses a rude lineation structure typical of a large, dome-like emplacement of granitic rock. The effects of any linear structures on the tunneling and design are described under Site A, Santa Catalina Mountains.

None of the structural conditions at this site is of major adverse effect to the deep-underground cavity, Site A.

The area, although generally considered to be seismically inactive, may experience some seismic events. Furthermore, although the granodiorite is geologically an extremely old rock, the Granite Mountain mass may have been uplifted in recent geologic time along the boundary faults described earlier. If this condition has occurred, further adjustment and uplift is possible; this should be considered in the design of any installation at this site.

Advantages of Proposed Tunnel Alignment

The alignment for Site A offers three major advantages:

a. The site is easily accessible and its portal is located a short distance from the Alaskan Highway.

b. Sufficient topographic relief is available to attain a cover thickness of 5000 feet within an access tunnel length of some 12,000 feet.

c. The deep-underground cavity is located within a uniform, massive, granitic rock.

Rock Conditions Anticipated Along Proposed Tunnel Alignment

The general conditions of the granodiorite anticipated along the access tunnel alignment are shown in Fig. 14. Within the near-surface zone of 1000 to 2000 feet, the granodiorite is expected to possess joints and fractures in abundance. Weathering has probably deteriorated the rock to depths of several hundred feet as well as along the fractures.

The portal of the tunnel, Site A, is located within the thin alluvial cover of the stream valley. The alignment may traverse up to 2000 linear feet of alluvium, outwash, lake beds, and glacial debris before encountering the granodiorite at depth. Alternate designs could eliminate any underground excavation in the alluvium, or else this portion of the access could be an open cut. As the depth of the granodiorite below the alluvium has only been estimated, some exploration will be required to determine the configuration and condition of this rock.

Beyond the near-surface zone, the tunnel should encounter massive, fresh granodiorite. Fractures and joints should be widely spaced. Some faults may be encountered within the granodiorite mass, but at depths below 2000 feet of cover, these faults, like the joint planes, are expected to be tight and to carry only minimal quantities of water.

An alternate access tunnel alignment is shown (15,500 feet in length) that is 3500 feet longer than the lower alignment. This alignment is wholly within the granodiorite and avoids traversing any alluvium and glacial debris in the portal section.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

Figures 14 and 15 show two possible alignments for access tunnels to a potential large deep-underground area beneath Granite Mountain. Both alignments are expected to encounter similar rocks along their access and within the subsurface area of the potential deep-underground cavity. No unusual conditions are anticipated within the area of the deep cavity; The occurrence of ground water along fractures is expected to be minimal.

Any areas of active tectonic stress which may be encountered are expected to be of moderate to low intensity.

Supports should not be required along an average-sized access tunnel, except in any fault zones or areas of high tectonic stress which may be encountered. Requirements for supports and reinforcement within the cavity area will be directly related to the size of the underground openings constructed.

Dominant Favorable Features of Deep-Underground Site

Site A beneath Granite Mountain includes the following desirable conditions for a deep-underground site:

a. Both the access tunnel and the cavity area are located within a massive, uniform, granitic rock.

b. The length of the access tunnel is less than 12,000 feet to be subsurface area with 5000 feet of cover.

c. A very large subsurface area with 5000 feet of cover is available.

d. The region of Site A was deformed by the emplacement of the granodiorite in ancient geologic time (Mesozoic) and since then has been uplifted as a large block by movement along the major faults bounding the mountain mass. Any tectonic stress that may remain within Granite Mountain should be of low intensity, but some areas may possess active tectonic stresses; geologic uplift in Tertiary time has elevated the granodiorite mass, and this more recent adjustment may have developed stresses that are partially retained within the mountain.

Adverse Features of Deep-Underground Site

On the basis of knowledge available from the geologic literature and reports on this area, this site is largely free of any adverse features. Small to moderate-sized fault zones undoubtedly occur throughout the granodiorite mass, but where encountered below 2000 feet of cover these fault zones are expected to offer no particular tunneling difficulties. The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

Granite Mountain, Big Delta Region, Alaska - Site B
(Latitude 63° 48', Longitude 145° 30')

Geographic Location and Accessibility

A second deep-underground site is proposed beneath Granite Mountain, Big Delta region, Alaska. This second access alignment, Site B, portals on the northwestern edge of Granite Mountain and trends S 46° E to a point beneath the main core of the granite mass. The areal setting of Site B is shown on the Locality Map in Fig. 15.

Site B is located some seven miles due east of the Richardson Highway at a point some 14 miles south of Delta Junction, or 24 miles south of Big Delta, Alaska. The site is easily accessible from the Richardson Highway over flat alluvial terrain, with a crossing of Jarvis Creek. At Delta Junction, the Richardson Highway joins the Alaskan Highway; airport facilities are also available.

Site Topography

The area of Granite Mountain is steep in terrain due to the numerous small canyons and ravines that have been carved on the flanks of the broad Granite Mountain. A description of the granite mass and sources of topographic data are described under Site A.

The access tunnel alignment, Site B, follows beneath a promontory ridge along the northeast flank of the mountain and extends to beneath the main flat-topped ridge of Granite Mountain. This access is 5000 to 6000 feet longer than the Site A alignment in order to attain a rock cover of 5000 feet.

Site B offers excellent underground potential, having an extremely large subsurface area with 5000 feet or more of cover rock.

Geologic Setting

This site is located in the northwestern part of the Granite Mountain area, which is roughly circular and is some 12 miles wide. The massive granite body is bounded on the south by a series of metamorphic rocks, primarily schist with some gneiss, as shown on the Locality Map in Fig. 15. The principal physical feature of the Granite Mountain mass is a broad domal uplift due to the intrusion of the granodiorite rock into the schist and gneiss series. Major fault zones bound the granite mass, as described below under Structural Features. Both Sites B and A are wholly within the granodiorite mass of Granite Mountain.

Rock Units of Site

Granodiorite. Granite Mountain consists of massive, coarse-grained granodiorite of Mesozoic age (Jurassic-Cretaceous) i.e., between 70 million and 135 million years old. The areal and regional relationships of this rock mass are described under Site A.

The granodiorite is anticipated to be in a fresh, massive, and generally high-quality condition at tunnel depths, as described in Fig. 15. The granodiorite varies in mineral composition from diorite to quartz diorite, and locally is extremely coarse to porphyritic in texture (Moffit, 1954[22]). This variation does not affect the strength and properties of this rock for underground construction.

Structural Features of Site

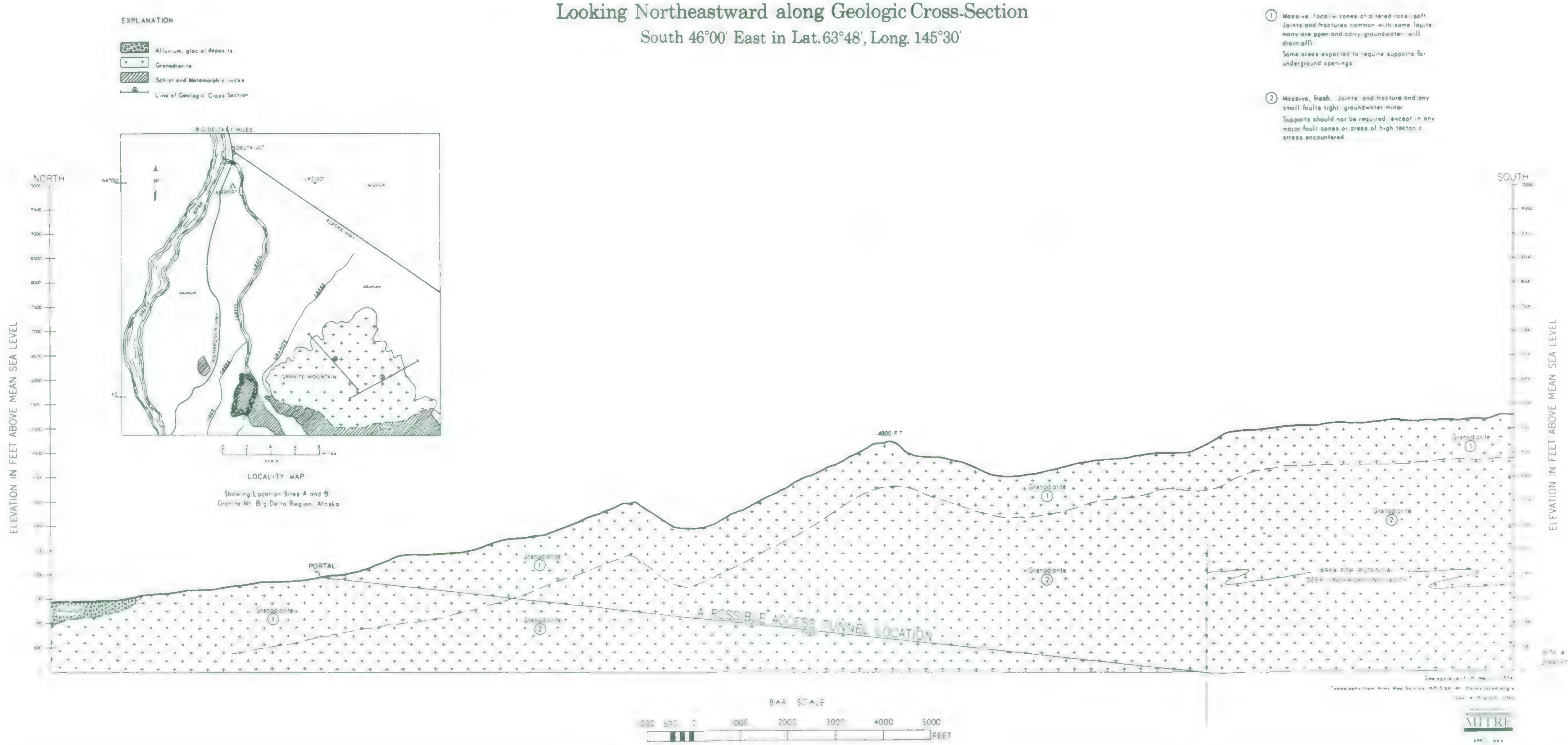
The Granite Mountain area is a domal uplift within a wide batholithic belt of Mesozoic granite. The principal structural feature of this site is the domal outline of the granodiorite. The importance of this feature and of the major fault zones occurring along the boundaries of Granite Mountain is described under Site A. Although a major fault zone is not shown on the geologic cross-section, such a fault probably occurs along the northwest flank of Granite Mountain, trending northeastward; this fault zone is located beneath the alluvium, or at an elevation well below the portal of Site B.

Undoubtedly, moderate- to small-scale faults occur throughout the granodiorite mass, as anticipated from the topographic features and history of similar intrusive rocks. A detailed geologic map of this area has not been prepared.

Fig. 15

GRANITE MOUNTAIN
BIG DELTA REGION, ALASKA Site B

Looking Northeastward along Geologic Cross-Section
South 46°00′ East in Lat. 63°48′, Long. 145°30′



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Areally, Site B is located within a large block up to 12 miles in width, bounded by a major fault zone on the northwest, the northeast and the southwest, and bounded by the intrusive contact with the metamorphic rocks on the southern boundary. It is probable that the granodiorite mass was mildly deformed during intrusion and now possesses a rude lineation structure typical of a large dome-like emplacement of granitic rock. Consequent effects on the tunneling and design of any linear structures are described under Site A, Santa Catalina Mountains.

None of the structural conditions at this site is of major adverse effect to the deep-underground cavity at Site B.

The area, although generally considered to be seismically inactive, may experience some seismic events. The possibility of this feature and its significance are discussed under Site A.

Advantages of Proposed Tunnel Alignment

The alignment of Site B offers three major advantages:

a. It is easily accessible over flat terrain, and its portal is located seven miles from the Richardson Highway.

b. The deep-underground cavity is located within a uniform, massive granitic rock.

c. Sufficient topographic relief is available to attain a cover thickness of 5000 feet. The access tunnel, however, is some 18,000 feet, or 5000 to 6000 feet longer than Site A.

Rock Conditions Anticipated Along Alignment

The general condition of the granodiorite anticipated along the access tunnel alignment is shown in Fig. 15. Within the near-surface zone of 1000 to 2000 feet, the granodiorite is expected to possess joints and fractures in abundance. Weathering has probably deteriorated the rock to depths of several hundred feet, as well as along the fractures.

Beyond the near-surface zone, as shown in Fig. 13, the tunnel should encounter massive, fresh granodiorite. Fractures and joints should be widely spaced. Some faults may be encountered within the granodiorite mass, but at depths below 2000 feet of cover, these faults, like the joint planes, are expected to be tight and to carry only minimal quantities of water.

Rock Conditions Anticipated in Vicinity of Deep-Underground Site

Figures 15 and 14 show two possible alignments for access tunnels to a potential large deep-underground area beneath Granite Mountain. Both alignments are expected to encounter similar rocks along their access and within the subsurface area of the potential deep-underground cavity. No unusual conditions are anticipated within the area of the deep cavity; any occurrence of ground water along fractures is expected to be minimal.

Any areas of active tectonic stress which may be encountered are expected to be of moderate to low intensity.

Supports should not be required along an average-sized access tunnel, except in any fault zones or areas of high tectonic stress which may be encountered. Requirements for supports and reinforcement within the cavity area will be directly related to the size of the underground openings constructed.

Dominant Favorable Features of Deep-Underground Site

Site B beneath Granite Mountain includes the following desirable conditions (similar to those of Site A) for a deep-underground site:

a. Both the access tunnel and the cavity area are located within a massive, uniform, granitic rock.

b. A large subsurface area with 5000 feet of cover is available. The length of the access tunnel is some 18,000 feet.

c. The region of Site B was deformed by the emplacement of the granodiorite in ancient geologic time (Mesozoic) and since then has been uplifted as a large block by movement along the major faults bounding the mountain mass. Any tectonic stress that may remain within Granite Mountain should be of low intensity, but some areas may possess active tectonic stresses; geologic uplift in Tertiary time has elevated the granodiorite mass, and this more recent adjustment may have developed stresses that are partially retained within the mountain.

Adverse Features of Deep-Underground Site

On the basis of knowledge available from the geologic literature and reports on the area, this site is largely free of any adverse

features. Small- to moderate-sized fault zones undoubtedly occur throughout the granodiorite mass, but where they are encountered below 2000 feet of cover, these fault zones are expected to offer no particular tunneling difficulties. The usual tunneling precautions and reinforcing supports will be required consistent with the accepted practice of deep-underground excavation.

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